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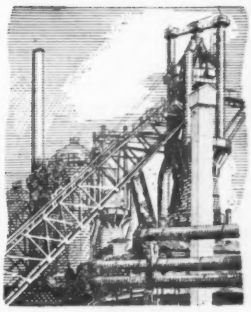

Studies of Blast-furnace Assessment

By J. M. Ridgion and A. M. Whitehouse

SYNOPSIS

For several years attempts have been made to establish the correlation between the many factors that control blast-furnace performance. Statistical techniques, such as multiple regression analysis, which involve the study of a large number of values relating to each factor, have been applied.

In order to condense the time required for the mathematical work, use was made of the Ferranti computer installed at Manchester University, and details are given of the results obtained from a study of seven furnaces. 1352

Introduction

THE STUDY OF DATA from operating blast-furnaces is of value in a number of ways. In the first instance it should provide a standard with which to appraise current performance of a furnace by taking into account the external conditions existing at the time. If, for example, the fuel consumption is unusually high, this may be due to a change in such measurable factors as burden yield and coke quality: it may, on the other hand, be due to a deterioration of conditions inside the furnace itself.

A second application is in estimating the effect of changes in raw materials supplies, burden preparation, and operating techniques, which may prove of considerable value in estimating the advantages of schemes of capital expenditure.

It is also to be expected that detailed studies of variations in furnace economy and productivity may assist in making comparisons between the performances of furnaces of differing size and design.

The present study is based on the application of the methods of mathematical statistics to routine operating data relating to a large number of factors which may be expected to have an influence on fuel consumption or productivity. As detailed further below, the blast-furnace is subject to so many variable factors that mathematical techniques of this type must be applied to large collections of data in order to isolate the effects of the individual variables. To date, seven furnaces have been studied using weekly data over periods varying from 1½ to 6 years. The number of factors studied in each case was of the order of 20 to 30, though many of these were subsequently found to be irrelevant.

The results of multiple regression analysis take the form of quantitative estimates of the effects of several variables on one variable, e.g. fuel consumption. Each of these estimates is independent of the effect of the other variables considered.

Many analyses, including different groups of variables, were performed and, while some inconsistencies arose, a consideration of all the equations obtained makes it possible to put forward the following coefficients as being definitely indicated by the work done. It is hoped that this summary will be of practical use to blast-furnace men:

An increase of 1 cwt/ton in total burden results in an increase of 0·15 cwt/ton in carbon rate.

An increase of 0·1 unit in CaO/SiO_2 in the slag results in an increase of 0·35 cwt/ton in carbon rate.

An increase of 100° C blast temperature results in a decrease of 0·4 cwt/ton in carbon rate.

An increase of 10% hard ore (at the expense of soft ores) results in an increase of 0·4 cwt/ton in carbon rate.

An increase of 10% sinter results in a decrease of 0·7 cwt/ton in carbon rate.

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Table I—MEANS AND STANDARD DEVIATIONS

Variable	Margam No. 1 (1947–51)			Clyde No. 1 (1943–49)		Redcar No. 1 (1948 and 1950–52)		Redcar No. 4 (1950–52)			Bessemer No. 5 (1951–54)			Sheepbridge No. 1 (1951–54)		Sheepbridge No. 2 (1953–54)	
	Mean	S.D.	S.D. Within Groups	Mean	S.D.	Mean	S.D.	Mean	S.D.	S.D. Corrected	Mean	S.D.	S.D. Corrected	Mean	S.D.	Mean	S.D.
Number of Weeks	210	210	210	352	352	189	189	143	143	170	147	147	124	147	147	74	74
Carbon rate, cwt/ton						15·87	0·96	16·92	0·815	0·51	17·83	1·63	0·70	17·96	1·22	19·41	1·27
Coke rate, cwt/ton	18·9	1·59	0·726	18·12	1·40												
Carbon consumption, 1000 tons/week						2·374	0·203	2·356	0·131		2·381*	0·187	0·089	1·944*	0·150	1·966*	0·170
Iron make, 1000 tons/week	4·071	0·556	0·139	3·238	0·335	3·010	0·287	2·793	0·217		2·717*	0·384	0·127	2·173*	0·205	2·033*	0·195
Ore + limestone, 1000 tons/week	10·696	1·803	1·070														
Total burden, cwt/ton				45·51	7·88	49·4	2·91	51·21	3·29	1·37	52·00	4·10	2·06	56·35	4·59	61·08	3·94
Hard ores, % of ores	56	12·05	6·54	25·05	19·56	41·60	19·83	37·27	9·7		34·6	11·7	4·3				
Wabana, % of ores				15·70	15·82												
Home ores, % of ores				31·01	38·30												
Raw Cleveland, % of ores						35·89	11·07	7·31	10·1		38·3	18·7	3·3				
Calcined Cleveland, % of ores						19·55	15·90	34·83	8·7		8·1	14·5	2·6				
Total Cleveland, % of ores											46·4	24·5					
Lump ores, % of ores														64·5	8·8	63·0	8·9
Screened ores, % of burden											36·7	24·8	7·6				
Sinter, % of burden				25·49	5·99	39·57	20·16	10·99	10·4		19·4	9·8	2·0	15·5	5·9	13·5	7·1
Scrap, cwt/ton				0·96	0·42	0·44	0·47	0·45	0·45		0·52	0·37	0·28				
Coke carbon, %	83·9	2·32	1·40														
Coke porosity, %											43·9	1·7	0·8				
Coke bulk density, lb/ft³											30·7	2·8	2·7				
Coke shatter index (1½ in.)											84·7	0·5	0·2	78·4	1·7	77·6	1·8
Bought coke, %	2·9	10·18	4·63	11·57	15·44												
Coke sulphur, %	1·07	0·099	0·071								1·30	0·03	0·02	1·21	0·09	1·27	0·08
Coke sulphur, % of iron						1·00	0·085	1·074	0·086	0·055							
Metal Si, %						0·78	0·13	0·77	0·10		1·22	0·15	0·10	2·23	0·74	2·51	0·76
Slag volume, cwt/ton	12·6	1·86	0·99			12·12	4·29	14·82	1·52								
Slag CaO/SiO₂						1·23	0·07	1·22	0·059	0·038	1·19	0·08	0·04	1·22	0·10	1·23	0·11
(CaO + MgO)/SiO₂ in slag	1·5	0·0452	0·0341			1·49	0·072	1·49	0·061		1·40	0·08	0·04	1·31	0·105	1·32	0·114
Al₂O₃/SiO₂ in slag	0·62	0·0246	0·0186			0·61	0·05	0·63	0·031					0·65	0·05	0·66	0·07
Blast temperature 1000° C	5·51	0·54	0·431			6·86	0·461	6·70	0·26	0·14	6·20	0·64	0·25				
Blast humidity, grains/ft³						3·35	0·91	3·36	0·95	0·29	3·34	0·90	0·34				
Blast volume, 1000 ft³/min	46·30	2·56	1·85														
CO/CO₂ in top gas	2·6	0·396	0·29			2·76	0·27	2·67	0·21								
Operational h/week											161·66	4·32	3·42				

*Corrected for lost time

An increase of 1% silicon in the metal results in an increase of 1·2 cwt/ton in carbon rate.

In considering any interpretation or application of these coefficients, it is essential to bear in mind that they may be expected to apply over normal operating ranges but will tend to break down if extrapolated right outside the range of normal working on which they are based.

It will be noted that changes in furnace practice may affect more than one of the variables tabulated above. For example, an increase in percentage of sinter may decrease the total burden and may also affect the blast temperature which the furnace can carry. In such a case the effects quoted will be additive.

It will be evident from a study of the detailed equations below that, for any given furnace, a set of coefficients can be derived which fit the data better than the average figures already given. In a number of cases other variables have proved to be of importance, so that future work may well result in the inclusion of additional figures in the list quoted above.

PROBLEMS OF BLAST-FURNACE ASSESSMENT

A study of the factors affecting blast-furnace performance is one of unusual difficulty in view of the very large number of factors operating simultaneously in an uncontrolled manner. Many of these show strong inter-relationships, so that variations in one factor may tend to obscure the effects of another. Moreover, not all these factors are available in a form suitable for analysis. Modern plants maintain extensive records of instrument readings and materials movement, but there still remain a large number of factors not susceptible to quantitative assessment. The accuracy of the available information, notably gas analysis and slag volume, frequently leaves much to be desired and this has restricted the choice further. The time unit of one week adopted for this work is in the nature of a compromise. Over a period much shorter than a week, it is not possible to assess the true output of iron from a furnace, owing to the variable amounts of material remaining in the furnace at the end of a cast. In addition much of the information is not normally available on a daily basis. Longer periods than a week have the disadvantage that the number of sets of data readily available becomes too small for reliable assessment of the significance of the results. Moreover, the averaging effect of a longer period will tend to obscure the relationships sought.

The technique of multivariate regression analysis selected consists essentially in expressing one variable, known as the dependent variable, as a function of a number of ' independent ' variables and implies that the value of the former is, in some sense, a result of the values of the latter. In the blast-furnace operation it is possible to take the view that the raw materials' characteristics, the fuel consumption, and the driving rate of a furnace are all determined by the operator, and the only truly dependent variable should be the iron quality and the smoothness of operation of the furnace. In practice, the furnace operator varies the proportion of fuel charged, for example, in order to maintain steady and acceptable operating conditions. It might be held, therefore, that in examining the influence of various factors on fuel consumption, the system under study is that of the furnace together with its manager, rather than the plant itself. On this basis, the main dependent variables examined have been the fuel consumption/ton of iron, the input of fuel in tons/week, and the production of iron in tons/week.

For the choice of independent variables, there exists a considerable volume of practical information on the qualitative effect of a number of factors and this has been freely drawn upon.

In a multiple regression equation, each coefficient purports to show the effect on the dependent variable of its associated factor, all the remaining factors of the equation being maintained constant. Great care must therefore be taken in the choice of independent variables if the coefficients are to have a rational physical meaning. In extreme cases it may be physically impossible for one of the independents to vary if the others are held rigidly constant.

In some cases two independent variables are so closely related to each other that it is essential to the performance of the regression analysis that only one should be included. This may account for the omission from some equations quoted later of what may appear very important independent variables. Thus, either the blast volume or the coke consumed per week could be used as an index of the rate of driving of the furnace; but, if they were simultaneously included as independent variables, the equations would be ' ill-conditioned ' and mathematical difficulties would probably arise.

The general result of inter-relationships between independent variables is that the value of a regression coefficient will depend numerically on what other independent variables are in the equation and hence effectively held constant. Equations with a large number of independent variables may therefore be expected to give more reliable estimates of the effect of the separate factors. In practice, however, the exclusion of variables which might lead to ill-conditioning, together with the exclusion of every variable subsequently shown to be mathematically non-significant, is apt to result in the production of two or more regression equations in which the coefficients for a particular variable differ. In such cases the choice between equations for practical application is best made on technical considerations of the process. As more analyses have accumulated, however, it has become possible to make closer estimates of what is hoped is the ' true ' effect of the independent variable in question.

Another difficulty which occurs in applying multiple regression analysis to blast-furnace data is the effect of long-term trends. Theoretically, multiple regression demands that each item of information should be independent of the others. This is by no means true of data which consist of weekly averages. Obviously one weekly average will tend to be related to the succeeding one. In addition there are often long-term changes in the general level of variables. It has been found in practice that this type of effect is more marked in some cases than in others, but in practically all cases the effect of these time trends has been present in some degree.

For example, if one of our independent variables

Table II—REGRESSION EQUATIONS RELATING TO FUEL CONSUMPTION

Variable	Coke Rate					Carbon Rate																		
	Margam No. 1		Clyde No. 1			Redcar No. 1		Redcar No. 4			Bessemer No. 5				Sheepbridge No. 1		Sheepbridge No. 2							
Number of Weeks	210	Trend Free 210	352	352	300	300	189	189	143	143	Corrected 170	147	Corrected 124	147	147	147	147	74	74	74	74	74	74	74
Carbon consumption, 1000 tons/week				+0·65 4			(+0·4) 1·7		(+0·8) 1·7															
Iron make, 1000 tons/week		−1·05 10									N													
Ore + limestone, 1000 tons/week	−0·123 2																							
Total burden, cwt/ton			+0·153 22	+0·148 13	+0·237 17	+0·142 7	+0·140 7	+0·084 4	+0·096 6	+0·096 4	+0·096 4	+0·156 7	+0·198 5	+0·277 17	+0·18 7	+0·132 7								+0·15 5	
Hard ore, % of ores	−0·0167 3	+0·011 2	+0·051 8		+0·030 8							+0·04 7	N	+0·049 7	+0·038 5	0·0								
Wabana, % of ores			+0·030 5		+0·030 8																			
Home ores, % of ores			+0·044 11																					
Raw Cleveland, % of ores												+0·076 8	+0·071 3											
Calcined Cleveland, % of ores												+0·072 8	+0·098 4											
Lump ores, % of ores														+0·035 3										
Screened ores, % of burden												−0·01 3	N	−0·017 5				N						
Sinter, % of burden				−0·077 8								−0·063 5	−0·090 4	−0·052 4		−0·083 5								
Scrap, cwt/ton				−0·72 4										−0·33 4		−0·23 2								
Coke carbon, %	−0·163 4	−0·104 4										−0·01 2	(−0·009) 1·7											
Coke porosity, %												+0·044 2	N											
Coke bulk density, lb/ft³														−0·16 3				N						
Coke shatter index (1½ in.)																								
Bought coke, %	+0·031 5	N +3·3 6		+0·055 17	+0·038 11									+2·6 3		N		N						
Coke sulphur, %						+4·26 7	+4·30 7	+3·79 6	+3·81 6	+5·88 10						N		N						
Coke sulphur, % of iron												+2·32 6	+1·12 2½	+2·32 6		+0·79 4		+1·25 5						
Metal Si, %	+0·314 9	+0·19 5																						
Slag volume, cwt/ton				+4·05 7	N	+2·67 3	+3·06 4	+3·39 4	+3·16 4	N		+2·60 2	(+2·18) 1·8											
Slag CaO/SiO_2																								
$(CaO + MgO)/SiO_2$ in slag	−6·45 4	N		+0·72 8	+0·18 2·2	+0·46 4	−0·22 2	−0·43 2	−0·42 2	−0·49 2		−0·50 4	(−0·28) 1½	−0·66 6		−0·13 3	−0·15 4	−0·33 4						
Blast temperature 100° C		N										−0·15 2	N											
Blast humidity, grains/ft³	N	+0·106 5																						
Blast volume, 1000 ft³/min	+1·645 11	+0·47 3½																						
CO/CO_2 in top gas		N										−0·038 3	−0·034 2½											
Operational h/week	18·9		18·12	18·12	17·79	17·79	15·87	15·87	16·92	16·92		17·83		17·83	17·83	17·96	17·96	19·41	19·41	19·41	19·41	19·41	19·41	19·41
Dependent variable. Mean, cwt/ton	1·59	0·726	1·40	1·40	1·17	0·96	0·96	0·96	0·815	0·815	0·51	1·63	0·70	1·63	1·63	1·22	1·22	1·27	1·27	1·27	1·27	1·27	1·27	1·27
Standard deviation, cwt/ton	0·58	0·48	1·11	0·79	0·85	0·62	0·65	0·55	0·58	0·58	0·40	0·62	0·50	0·75	0·82	0·57	0·67	0·96	0·96	0·96	0·96	0·96	0·96	0·96
Residual standard deviation, cwt/ton	87	60	38	68	47	69	58	54	55	53	39	85	50	79	75	53	45	42	54	54	54	54	54	54
Variance accounted for, %																								

and our dependent variable both show a marked tendency to rise in level steadily over the whole period under review, this will show as a correlation between the two. It may, however, not be a real association at all, the rise in each case being due to causes not connected with the operation of the furnace, such as general economic conditions. If the relationship between the two variables is real, it should show up when short periods are studied in isolation.

A statistical method was evolved using this principle. It consisted in dividing the whole period under review into six-weekly blocks. The difference of each variable from the mean of its block was then taken as the basis for the multiple regression. This method has been applied to several regressions quoted below. The differences between the resultant equations and those where trend elimination was not applied are some indication of the extent to which time trends are influencing the results.

This method provides coefficients of a different nature from the normal method. They are short-term coefficients which can be applied only in comparing the results of one period with those of periods near to it in time. They cannot be used for predicting the effect of radical changes in any of the independent variables.

For purposes of week-by-week control of the furnace, the short-term coefficients should be used, but, for explaining long-term variations in furnace performance or predicting the effect of changes in practice, the normal coefficients may be more accurate.

Multiple regression analysis is a fundamentally simple procedure, but the computations become rapidly more laborious as the number of variables and the number of observations increase. As the present work has developed, therefore, increasing recourse has been had to modern high-speed computing facilities. In the solution of the regression equations, the amount of computing work varies approximately as the cube of the number of variables handled, and the more conventional desk-machine techniques reach an effective limit with about eight variables; modern electronic computers virtually abolish this limit. The extensive range of variables encountered in the blast-furnace problem make it essential to use these facilities in any general survey work. Most of the work was carried out on the Ferranti computer installed at the Computing Machine Laboratory of the University of Manchester, and a detailed instruction programme for regression analysis was worked out and applied to this machine.*

DATA AND RESULTS

Selection of Variables

Furnaces at five plants have been studied using data in the form of routine weekly records. The variables considered in each case are set out in Table I, which shows mean values for the period examined, together with standard deviations. It will be observed that the selection of variables is by no means the same in all cases. This is due in part to certain values not having been recorded—detailed figures of coke properties are not to be expected at a plant using a score of cokes from different sources—and in part to changes of emphasis as the work has proceeded. The computing facilities employed have also influenced the number of variables handled throughout the investigation. Sums of products and squares were evaluated by Hollerith punched-card equipment for Clyde No. 1 and by matrix multiplication on the Manchester University computer for Margam No. 1, the regression analysis being subsequently effected by desk calculating machines using methods of the Doolittle or Choleski type. For the remaining furnaces, full use was made of the Manchester University machine for all stages of the work, and larger numbers of variables could therefore be used.

The most important dependent variable has been the fuel consumption in coke or carbon per unit of iron made. In several cases, carbon per week as an index of driving rate, and iron production have been introduced as dependents. Various supplementary studies of flue-dust production, sulphur partition, etc. have been made, but the somewhat fragmentary results are not discussed here.

The choice of independent variables for the coke-rate equations has been the subject of much study and a variety of combinations has been used at various stages of the work, the results presented below being a selection of the more interesting ones.

The main variables employed can be grouped as follows:

Coke Quality Variables—Percentage fixed carbon has been used either as an independent variable or as a correction factor in deriving carbon rates. Percentage sulphur has been used frequently as an independent variable. Physical properties have, in general, been included where available; in their absence the percentage bought coke has been used in the case of firms using varying proportions of home-produced coke.

Burden Variables—As an index of richness of the burden, it is possible to use either the total weight of burden per ton of iron or the slag volume. In several cases the former has been preferred, as doubt has been felt about the accuracy of the slag figure. Iron content apart, the furnace performance is affected by the physical characteristics and reducibility of the burden constituents. This has been taken into account by including such factors as percentage hard ores, home ores, sinter, and lump ores, the selection being governed by the peculiarities of the practice in each case. In one instance the flue-dust make has been used as a factor influencing the actual smelting load on the furnace.

Product Variables—Silicon content of the iron and basicity functions of the slag are examples of this group which have been used in several cases.

Driving Index Variables—Coke or carbon consumption per week has been used in most cases in preference to blast volume, which is not always known with equal reliability. In one case the iron production serves this purpose; the total burden charged per week is also related to the driving rate.

* D. G. Owen and J. M. Ridgion: "A Multivariate Regression Analysis Programme for the Ferranti Computer at Manchester University," B.I.S.R.A. Report OR/1/54: 1954.

Table III—REGRESSION EQUATIONS FOR CARBON CONSUMPTION PER WEEK

Variable	Redcar No. 1		Redcar No. 4		Bessemer No. 5		Sheep-bridge No. 1	Sheep-bridge No. 2
Number of Weeks	189	189	143	143	Normal 147	Corrected 124	147	74
Carbon consumption, tons/week								
Total burden, cwt/ton	(+10) *1·8*		−10 *3*					
Hard ores, % of ores		*N*	+4·0 *3*	+3·9 *4*	+6·9 *7*	+6·4 *4*		
Raw Cleveland, % of ores		*N*	+6·6 *4*	*N*				
Calcined Cleveland, % of ores		−2·6 *9*	+3·9 *2½*	*N*	+4·8 *5*	*N*		
Lump ores, % of ores							*N*	+8·5 *4*
Screened ores, % of burden		*N*		*N*	+4·6 *10*	*N*		
Sinter, % of burden		*N*	−7·2 *8*	−6·0 *7*			*N*	−8·4 *3*
Scrap, cwt/ton				*N*	−72 *2·6*	*N*	*N*	+44 *3*
Coke porosity, %					+28 *3*	(+14) *1·6*		
Coke bulk density, lb/ft³								
Coke shatter index (1½ in.)							*N*	*N*
Coke sulphur, %							*N*	*N*
Coke sulphur, % of iron	−460 *2½*							
Metal Si, %		−94 *3*		*N*	−144 *2*	*N*	*N*	+123 *N*
Slag CaO/SiO_2	*N*			−493 *3*	−990 *5*	(−340) *1·8*	−257 *2·1*	*N*
$(CaO + MgO)/SiO_2$ in slag				*N*			*N*	*N*
Al_2O_3/SiO_2 in slag				*N*			*N*	*N*
Blast temperature 100° C	−85 *2·2*	*N*	+160 *4*	+160 *5*	*N*	(+51) *1·6*		*N*
Blast humidity, grains/ft³	*N*	*N*	−20 *2*					
Operational h/week					−7 *3*	−6 *3*		
Dependent variable. Mean, 1000 ton/week	2·374	2·374	2·356	2·356	2·381*	...	1·944*	1·966*
Standard deviation, 1000 ton/week	0·203	0·203	0·131	0·131	0·187	0·089	0·150	0·170
Residual standard deviation, 1000 ton/week	0·198	0·200	0·092	0·093	0·133	0·081	0·145	0·129
Variance accounted for, %	8	3	51	50	63	17	3	42

* Corrected for lost time

Operating Variables—Blast temperature has been widely used; its effects are by no means straightforward, but it is obviously associated with the efficiency of utilization of hearth heat. Blast humidity has been noted in certain cases. Time off-blast has been used as a variable in its own right and has also been used as a correction factor for coke and iron weekly figures. Weeks with less than 150 h operating time have, in general, been rejected. CO/CO_2 ratio in the top gas has been used in one case.

For any one equation, a selection of variables has been made, care being taken to avoid the inclusion of pairs showing high mutual correlation; for example, either total burden or slag volume has been used as a measure of iron content of raw materials, but not both. Precautions have been taken to ensure that the partial regression coefficients to be evaluated shall have a valid physical meaning. The advice of blast-furnace operators has been sought and obtained in selecting variables.

Regression Equations

Tests of statistical significance were applied to all the regression coefficients, and only those which could be regarded as significant at the 0·05 level were retained. At this (arbitrary) level of significance, there is a 95% chance that the true value of the coefficient in question lies between zero and twice the calculated value. The test is applied by evaluating the ratio t of the coefficient to its standard error: t = approximately 2 corresponds to 95% significance, and higher values of t mean greater certainty as to the true values of the coefficients. Variables for which $t < 2$ were eliminated from the set in later work by the computer during the course of the calculation, and a new equation was developed for the remaining variables.

Tables II–IV show the final coefficients thus obtained with the corresponding t value in italic type. Variables used in the original equation and subsequently found to be non-significant are indicated by *N*. In a few cases bracketed figures show coefficients in the range $2 > t > 1{\cdot}5$ where these are of interest.

For each final equation there are shown the initial and residual standard deviations for the dependent variable together with the percentage of the variance accounted for by the equation.

Trend Elimination

The Margam No. 1 analysis was carried out with the particular aim of investigating the effect of trends in the data, using the analysis of variations within six-weekly blocks previously referred to. Subsequent to this work a somewhat similar technique, employing differences from moving five-week averages instead of six-week fixed averages, was used in the cases of Redcar No. 4 and Bessemer No. 5, examples of which appear in Tables II, III, and IV.

Coke or Carbon Rate (Table II)

Considering first the equations in which time trends have been ignored, it is of interest to note the last two lines of the Table which give a measure of the goodness of fit and the degree of success in explaining the variations in the actual fuel consumption. The proportion of variance which can be accounted for on each furnace varies from about 50% to 85%, but it is noteworthy that the higher figures in this range are associated with high initial variances. In other words, the higher the variation is, the more can be accounted for. The residual variations in consequence tend to approximate to a lower limit of about $\frac{1}{2}$ cwt of carbon per ton of iron, which may be a consequence of inaccuracies in the routine records employed.

In all cases the total burden figure is seen to be highly significant. The coefficients relating to burden constituents vary considerably in significance but, where significant results appear, they confirm the adverse effect of hard ores and home ores and the beneficial effects of burden preparation. Physical test data on coke were available in few cases and then proved to have little or no demonstrable effects. Even the significant effects of porosity and bulk density (Bessemer No. 5) represent very small numerical influences on the fuel rate.

The influence of slag basicity is quite marked, amounting to about $\frac{1}{3}$ cwt of carbon for an increase in CaO/SiO_2 of 0·1 unit.

Blast-temperature effects are obscure, some furnaces even showing an increase in carbon rate with temperature. This is probably due to the use of blast-heat changes to correct adverse furnace conditions. If a furnace is running cold, it is not unusual to increase the coke rate (i.e. decrease the burden ratio) and to raise the blast temperature, at least for a period. Frequent occurrence of such a state of affairs could lead to positive correlation between fuel consumption and blast temperature.

Time-trend Effects

The elimination of time trends leaves many coefficients almost unaltered, but, in other cases, highly significant coefficients are completely eliminated in the trend-free equations. There seems to be some tendency for the same factors to be affected by trends in various works and using various dependent variables. Blast humidity and percentage hard ores are examples. The first is obviously a variable which is uncontrollable and subject to seasonal trends. Blast temperature, on the other hand, which is artificially controlled, appears to be practically unaffected by trends. Many other coefficients have lost all significance on elimination of trends and these have been taken to be due to coincidental long-term trends in variables and given little weight in assessing the overall results.

Driving Rate—Carbon per Week (Table III)

A general survey of the coefficients in Table III suggests that little light is thrown on the causes of changes in rate of driving. The two Redcar furnaces and the two at Sheepbridge are similar pairs, but results of analysis are widely divergent with very different residual variances and a seemingly random selection of significant coefficients. In this connection the results from Bessemer No. 5 are interesting; 63% of the variance is accounted for in the normal way with no less than eight significant variables. Application of the corrections for time trends eliminates four of these variables and reduces the accounted for variation to a mere 17%.

Table IV—REGRESSION EQUATIONS FOR IRON MAKE

Variable	Redcar No. 1	Redcar No. 4		Bessemer No. 5			Sheepbridge No. 1		Sheepbridge No. 2	
Number of Weeks	189	143	143	Uncorrected 147	Corrected 124	Uncorrected 147	147	147	74	74
Carbon consumption, tons/week	+0·95 *18*	+1·06 *16*				+1·20 *18*	+0·89 *15*		+0·98 *14*	
Total burden, cwt/ton	−28 *6*	−13 *5*	−42 *9*	−26 *5*	−23 *6*	−42 *15*	−16 *8*		−15 *5*	
Hard ores, % of ores			*N*			−7·8 *7*				
Raw Cleveland, % of ores			+850 *6*	−14 *7*	−19 *5*	−6·5 *6*				
Calcined Cleveland, % of ores			*N*	−8 *4*	−20 *4*					
Lump ores, % of ores							−3·5 *3*	*N*	*N*	+6·0 *2½*
Screened ores, % of burden				+7 *10*	+2 *2*					
Sinter, % of burden			−10·8 *8*	+6 *2*	*N*		*N*	+7·6 *3*	*N*	
Scrap, cwt/ton								+50 *4*		+50 *3*
Coke porosity, %				+42 *4*	+37 *3*					
Coke bulk density, lb/ft³				−14 *3*	*N*					
Coke shatter index (1½ in.)								+33 *3*		*N*
Coke sulphur, %								−640 *4*		*N*
Coke sulphur, % of iron	−870 *6*	−657 *7*								
Metal Si, %				−580 *6*	−400 *4*	−380 *5*	−108 *5*	*N*	−98 *5*	*N*
Slag CaO/SiO_2	−505 *3*	−580 *4*		−1840 *7*	−990 *4*		*N*	−400 *3*	*N*	*N*
$(CaO + MgO)/SiO_2$ in slag										
Al_2O_3/SiO_2 in slag										
Blast temperature 100° C	−100 *3*	+100 *3*	+260 *5*	+75 *3*	+180 *5*	+120 *7*	+65 *4*	+31 *2*	+40 *2*	*N*
Blast humidity, grains/ft³	+27 *2·3*	+23 *3*		+56 *4*	*N*					
Operational h/week										
Dependent variable. Mean, 1000 ton/week	3·010	2·793	2·793	2·717*	2·717*	2·717*	2·173*	2·173*	2·033*	2·033*
Standard deviation, 1000 ton/week	0·287	0·217	0·217	0·384	0·127	0·384	0·205	0·209	0·195	0·195
Residual standard deviation, 1000 ton/week	0·138	0·092	0·136	0·143	0·095	0·120	0·100	0·159	0·083	0·175
Variance accounted for, %	77	84	60	86	44	90	76	40	82	20

* Corrected for lost time

It may be concluded, therefore, that the variations in driving rate are due to factors other than those employed in this analysis. Probably factors not susceptible of quantitative assessment are involved, such as regularity of stock descent, extent of the zone of slag formation, and fusion, etc.

Iron Production (Table IV)

It is profitable to look on this variable as the ratio:

$$\frac{\text{Carbon consumed (tons/week)}}{\text{Carbon rate (tons/ton of iron)}}$$

The previous sections have shown that the array of independent variables used in this work can be used to give fairly close estimates of the carbon rate but no reliable indication for carbon per week.

Equations for iron make, which include ' carbon per week ' as an independent variable, may, by begging the question as to the causes of variations in driving rate, be expected to be as successful as the corresponding carbon rate equations. Table IV shows that this is so and that the regression coefficient for carbon per week approximates to unity, as one would expect.

One or two equations which exclude carbon per week from the list of independent variables have been shown in Table IV. The absence of an adequate basis for estimating driving rate inevitably results in poorer correlations and odd distributions of significant factors (Redcar No. 4). Time-trend elimination also reduces the figure of variance accounted for very markedly.

CONCLUSION

In surveying the results presented in Tables II, III, and IV, it is important to remember that one encounters a large amount of unexplained variation in a blast-furnace and that each individual coefficient obtained is in the nature of a sample value from the many that could have been obtained. Nevertheless, the action of blast-furnaces is, to some considerable extent, systematic and ultimately, as more furnaces are studied, a firm picture should begin to emerge. It is felt that a useful stage has been reached with regard to the effect of various factors on fuel consumption, and accordingly the equations have been reviewed and the values given on pp. 249 and 251 are presented. No such values can be given for the coefficients relating variables to carbon consumption per week and iron make.

On technical grounds, all the factors in Table I are suspected of influencing fuel consumption. One function of the list on pp. 249 and 251 is to select those which have actually been found to influence fuel consumption; the remainder are unlikely to have any important influence within the range experienced. It is of course possible that other factors which are not measured may later prove to have appreciable effects.

The main value of this list of coefficients is the quantitative estimates which it gives of the separate effects of each factor on fuel consumption.

Such a list of coefficients can be used in two ways:

Control

An equation can be evolved, using the coefficients, and applied week by week, so as to give the expected fuel rate when the factors included are taken account of. This is a step forward in explaining and controlling weekly variations in the fuel rate.

It is felt that the coefficients given on pp. 249 and 251 are accurate enough for use in this way.

Planning

With an extension of the work, it should be possible to improve this list of coefficients to an extent where it can be used with confidence to assess the effect of changes in policy, practice, or furnace design.

Acknowledgments

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Alloy Carbides Precipitated during the Fourth Stage of Tempering

AN ELECTRON MICROSCOPIC EXAMINATION

By Kehsin Kuo

SYNOPSIS

The appearance of freshly precipitated MoC_2, VC, TiC, and Cr_7C_3 has been examined both *in situ* and in the extracted state by means of the electron microscope, and the changes in structure and in hardness, especially the secondary hardening phenomenon, have been correlated.

For a constant tempering time of 1 h, the precipitation of minute Mo_2C, VC, and TiC 'threads' (about 30Å dia. and 200Å long) at 500–600° C causes an increase in hardness, and their growth into needles, discs, and spheroids above 600° C causes a decrease. The Cr_7C_3 carbide is formed in the same temperature range and grows very rapidly. This possibly explains why chromium steels commonly show no secondary hardening. 1337

Introduction

THE TEMPERING of quenched carbon steels can be roughly divided into three stages :

(i) Precipitation of ε-iron carbide and a low-carbon martensite (below 150° C)
(ii) Decomposition of retained austenite into bainite (150–280° C)
(iii) Precipitation of cemenite (above 200° C).

In certain alloy steels an alloy carbide may form on tempering, depending upon the kind and amount of the alloy element present. Since the nucleation and growth of an alloy carbide requires the diffusion of the alloy element in question, which is relatively slow at temperatures below 500° C, the fourth stage of tempering, i.e. the conversion of cementite into an alloy carbide, generally does not take place after short tempering below this temperature.

In medium- and high-alloy steels the precipitation of an alloy carbide is very often accompanied by an increase in hardness, which is commonly called *secondary hardening*. This correlation of the change in hardness and the change in structure was first pointed out by Bain and Jeffries[2] in their pioneer work on the red-hardness of high-speed steel. Houdremont, Benneck, and Schrader[3] later confirmed this hypothesis, by proving the precipitation of VC to be the cause of the secondary hardening observed in vanadium steels. Since then a great number of papers have been published showing the individual effect of titanium, vanadium, chromium, molybdenum, and tungsten on the formation of alloy carbides, and on the change in hardness during tempering. These papers will be referred to later in the discussion of the effect of each element.

Though the precipitation of an alloy carbide during the fourth stage of tempering is proved beyond any doubt by X-ray diffraction methods, the correlation of the changes in properties and in structure remains unsatisfactory. If the tempering time is kept constant at 1h, the hardness of high-alloy steels begins to increase at about 500° C, reaches a maximum at 550–600° C, and falls rapidly above 625° C, but the presence of an alloy carbide is commonly not detected by X-rays until the tempering temperature reaches 600–650° C. However, this is by no means unexpected, because the X-ray diffraction methods are not sensitive in dealing with a phase where the particles are extremely small (<1000 Å), and the carbide particles, during precipitation, must be very small indeed if they are able to cause an increase in hardness. Moreover, the precipitation of an alloy carbide is gradual, and its amount increases with tempering time or temperature at the expense of cementite. In other words, a small amount of alloy carbide coexists with a large amount of cementite in the early stage of this reaction. This will make the identification of the alloy carbide even more difficult. The electron diffraction technique may overcome the difficulty of small particle size, but even this method is insensitive in dealing with a phase present as a minor constituent in a mixture.

In a previous microstructural study[4] of the carbide phase-changes on tempering a molybdenum steel with 0·11% C and 2·14% Mo, it has been shown that the electron microscopic examination of extracted carbide provides more detailed information concerning this phase-change than any other method. On account of its acicular shape and small size (about 30 Å dia. and 200 Å long), the Mo_2C carbide precipitated between 500° and 600° C can easily be differentiated from cementite particles (average size about 1000 Å) in the extracted carbide residue (Fig. 1). A fairly good correlation between the change in hardness of the steel and the precipitation and growth of the Mo_2C carbide has been obtained by this means

This method has the advantages of high sensitivity and of being simple in operation, but it gives no insight into the mechanism of the conversion of cementite into an alloy carbide, nor does it show the

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Mr. Kuo, who was at the Department of Metallography, Royal Institute of Technology, Stockholm, when this work was carried out, is now with the Institute of Metal Research, Academia Sinica, Shenyang, Mukden, China.

Fig. 1—Steel *Mo*1, tempered at 600° C. A large amount of minute Mo_2C 'threads' (about 30 Å dia. and 200 Å long) mixed with a small amount of large Fe_3C particles (about 1000 Å) ×100,000

distribution of carbide in the steel. Therefore the Mo_2C carbide has also been examined in an extraction replica, as if the carbide particles were *in situ* in the steel specimen (Fig. 2). For some unknown reason, it has not been possible to obtain a satisfactory extraction replica with extremely small carbide particles, and so the use of this technique has been confined to structures obtained by tempering above 700° C.

Similar investigations have later been carried out on vanadium, titanium, and chromium as well as on a high-molybdenum steel, and the results are presented in this paper, which deals only with the appearance of carbides occurring between 450° and 750° C during the cementite → alloy-carbide conversion, and with its influence on the secondary hardening. The effect of alloy elements on the resistance to tempering, or softening, between 200° and 450° C is outside the scope of this paper.

EXPERIMENTAL METHODS

The composition of the steels used in the present investigation is shown in Table I. At the austenitizing temperature indicated in this table, the carbide particles were completely dissolved in the austenitic matrix. After quenching in water and liquid air, the steel specimens were tempered at various temperatures for a constant time of 1 h.

Carbides were extracted from steel specimens by dissolving the ferrite either chemically or electrolytically; the former method[5] involved dipping for 10 s in HNO_3 (1 : 1), and the latter a 30-s electrolysis in

Fig. 2—Steel *Mo*1, tempered at 700° C. Extraction replica micrograph showing the distribution of Mo_2C needles in an austenite grain; apart from lying on parallel planes, Mo_2C shows no preferred orientations ×12,000

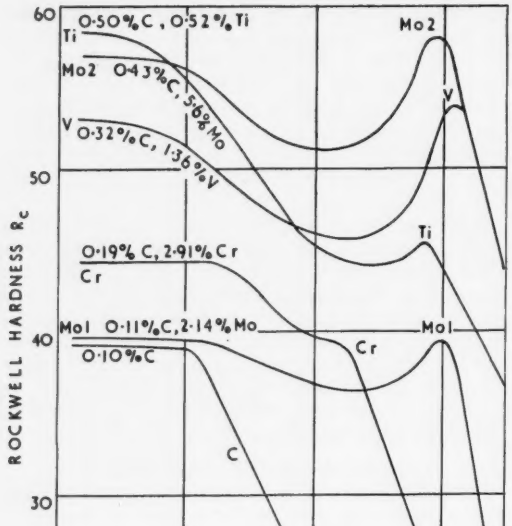

Fig. 3—Change of hardness with tempering temperature (tempering time 1 h)

HCl (1 : 20), at a current density of 0·1 A/cm². These two methods gave similar results. After washing in water, alcohol, and isoamyl acetate the carbide particles were freed from the steel specimens by supersonic vibrations and a suspension in isoamyl acetate was thus obtained. A drop of this suspension was allowed to dry on a thin Formvar film supported by a copper grid, and this was examined in the electron microscope.

It is known that the ordinary replica stripped from the steel specimen is very often contaminated with carbide particles dislodged from the polished surface,[6] and this is especially pronounced in alloy steels.[7, 8] This contamination has been utilized deliberately by Rizol and Utelskii[9] to study the appearance of carbide in chromium steels, and by Wever and Schrader[10] and by Kuo[4] to study the appearance of Mo_2C in molybdenum steels. Fisher[11] first used the term 'extraction replica,' though he has employed a second etching through the replica to achieve this end. The replica used in the present investigation was made of Formvar according to the method described elsewhere by H. and S. Modin.[12]

Rockwell hardness measurements were made on the same specimens from which carbide had been extracted for the electron microscopic examination.

HARDNESS MEASUREMENTS

The change in hardness of these steels with increasing tempering temperature (for a constant time of 1 h) is illustrated in Fig. 3, from which the following observations can be made:

(i) As is well known, the as-quenched hardness depends mainly, if not entirely, on the carbon content of the steel, provided that the austenitizing temperature is high enough to dissolve all carbides before quenching. In other words, the presence of alloying elements does not affect the as-quenched hardness of low- and medium-carbon steels. (In high-carbon steels, the amount of retained austenite, and therefore also the as-quenched hardness, may in some cases be influenced by the alloying elements.)

(ii) Below 150° C there is almost no change in hardness in these steels, possibly because of their low or medium carbon contents.

(iii) Between 200° and 450° C, i.e. within the temperature range of the precipitation and growth of cementite, alloy elements retard softening caused by tempering. When present in sufficient amount, these alloy elements are about equally effective in retarding softening. In the present case, the amount of titanium in steel *Ti* is not enough to combine with all the carbon, and therefore the retarding effect is not so obvious. However, earlier investigations[13, 14] have shown very clearly that titanium, when present in sufficient amount in austenite before quenching, exhibits a retarding effect similar to that of vanadium.

It is the common opinion that cementite coagulates more sluggishly in alloy steels, and this may perhaps account for their increased resistance to tapering. However, a careful examination of the size and shape of extracted cementite formed at 350–450° C in carbon as well as in alloy steels, undertaken by the present author, did not reveal any marked difference between these two kinds of cementite. The difference in size is too slight to justify the suggestion that this accounts for the marked difference in tempering behaviour between carbon and alloy steels.

(iv) Secondary hardening occurs in molybdenum, vanadium, and titanium steels, but not in chromium steels, whose hardness instead drops rapidly above 450° C. Increasing the chromium content to 12% may impart to a steel a fairly constant hardness up to 500° C, but above this temperature there is rapid

Table I

CHEMICAL COMPOSITION AND AUSTENITIZING TREATMENT OF STEELS

Steels	Chemical Composition, %									Austenitizing Treatment Temperature, °C	Time, min
	C	Si	Mn	P	S	Mo	V	Ti	Cr		
Mo1	0·11	0·08	0·12	...	...	2·14	...	...	...	1150	30
Mo2	0·43	0·16	0·31	0·009	0·013	5·6	...	...	...	1250	10
V	0·32	0·33	0·34	0·012	0·009	...	1·36	...	...	1250	10
Ti	0·50	...	...	...	...	...	...	0·52	...	1250	10
Cr	0·19	...	...	...	...	...	...	...	2·91	1150	30

softening.[15,17] Bain[15] found a slight increase in hardness at 470° C in a steel with 0·35% C and 12% Cr, but the cause of this rehardening is not necessarily the precipitation of a chromium carbide, since Rickett *et al.*[17] have shown that this increase in hardness can also occur in a 12% Cr steel with as little carbon as 0·016%.

Anyhow, there seems to be a marked difference in rehardening capacity between molybdenum, vanadium, and titanium (possibly also tungsten) steels on the one hand and chromium steels on the other, in spite of the fact that the carbide conversion, cementite → alloy-carbide, takes place in all these steels between 500° and 650° C. This will be further discussed in connection with the electron micrographs of extracted carbide.

(v) Analogously to the rapid decrease in hardness in a carbon steel between 250 and 450° C, the hardness of molybdenum, vanadium, and titanium steels drops considerably between 625 and 700° C.

MOLYBDENUM STEELS

The appearance of Mo_2C formed on tempering a quenched low-carbon molybdenum steel (*Mo*1) has been studed before,[4] and Figs. 1 and 2 are reproduced here to illustrate the needle-like shape of this carbide. This steel was chosen because it has an atomic Mo : C ratio of about 2, so that the conversion of Fe_3C into Mo_2C can take place rapidly and completely, and because it has a low carbon content, so that the amount of retained austenite is extremely small and the secondary hardening phenomenon therefore is attributable solely to the precipitation of the Mo_2C carbide. It has been shown that for a constant tempering time of 1 h the precipitation of acicular Mo_2C in this steel begins at 500° C, attains its maximum at 600° C (Fig. 1) and finally ceases at 650° C, and that the growth of Mo_2C is obvious only above 600° C, appearing to be most rapid between 650° and 700° C (Fig. 2). The precipitation of Mo_2C is accompanied by an increase in hardness and its growth by a rapid decrease (Fig. 3). In the meantime, cementite dissolves and disappears completely above 600° C.

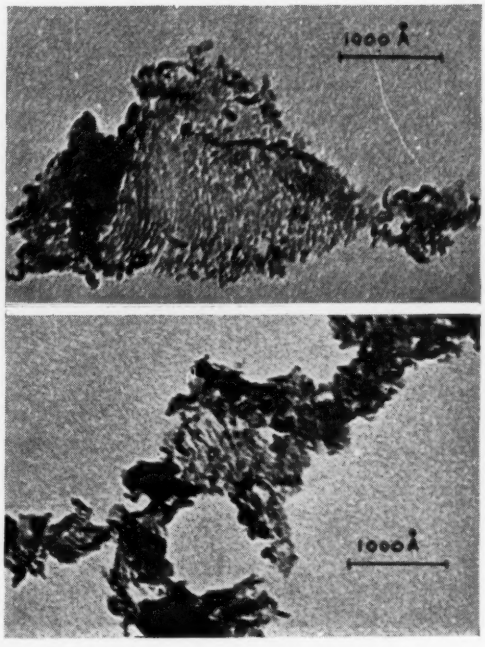

Fig. 4—Steel *Mo*2, tempered at 600° C. Mo_2C ' threads ' in parallel alignment ×150,000

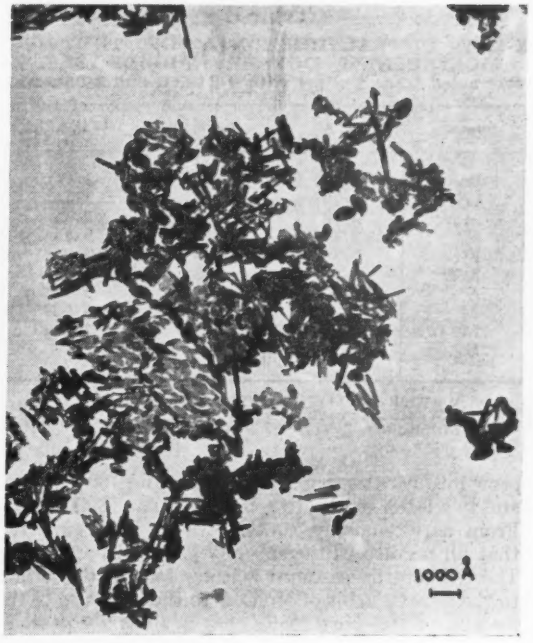

Fig. 5—Steel *Mo*2, tempered at 700° C. Mo_2C ' threads ' have grown to needles (about 200 Å dia. and 1000 Å long) and spheroids (about 500 Å dia.) ×50,000

The same microstructural changes also occurred in steel *Mo*2 with 0·43% C, 5·6% Mo, and a Mo : C ratio of 1·62. However, the extracted Mo_2C ' threads ' formed between 500° and 600° C very often showed parallel alignment with the appearance of fine lamellar pearlite (Fig. 4). The possibility of producing this alignment during extraction and preparation of the sample for electron microscopic examination must be very small indeed, if it does exist at all. Moreover, such a parallel formation of cementite needles has recently also been found by Modin in a eutectoid carbon steel tempered for 1 s at 400° C, and by the present author in a vanadium steel (steel *V*) tempered for 1 h at 450° C (Fig. 6). Therefore, this alignment of carbide is considered to be a true structure existing in the steel during the early stage of precipitation of Mo_2C. Since this alignment can be extracted intact without falling apart, it is suggested that the carbide ' threads ' are internally connected. The growth of one ' thread ' may stimulate the nucleation of others, and finally they grow together. This seems to be connected with the medium carbon content of this steel. In low-carbon molybdenum steels the Mo_2C ' threads ' are so widely separated that there is very little chance for them to grow together. At 600° C the Mo_2C ' thread ' is about 30 Å dia. and 200 Å long.

Figure 5 shows that the Mo_2C ' threads ' eventually

Table II

X-RAY DIFFRACTION DATA OF THE NEW MOLYBDENUM DOUBLE CARBIDE M_aC_b
Extracted from a Steel with 0·24% C and 2·85% Mo

Intensity	*d*, Å	Intensity	*d*, Å
W	2·76	M	2·11
W	2·70	VS	2·08
MW	2·48	MS	2·06
M	2·46	W	2·05
MS	2·34	MS	2·01
MW	2·28	MS	1·990
S	2·27	W	1·912
M	2·20	S	1·883
M	2·19	W	1·812
S	2·15		

W: Weak
MW: Medium weak
M: Medium
MS: Medium strong
S: Strong
VS: Very strong

grow into needles (about 200 Å dia. and 1000 Å long) and to a lesser extent to spheroids (about 500 Å dia.). From surface-energy considerations, it is expected that all needles will eventually grow into spheroids. The temporarily assumed acicular form is due either to the growth habit of Mo_2C or to the influence of the matrix. Since pure Mo_2C does not usually grow in an acicular manner, the latter explanation perhaps is more probable, especially since this carbide, as discussed below, is considered to precipitate coherently from the iron matrix.

That the acicular phase extracted from steel specimens tempered above 600° C is the Mo_2C carbide has been confirmed by both X-ray and electron diffraction methods. Owing to the small particle size of this carbide, its X-ray diffraction pattern is rather diffuse. Moreover, it seems that the diffraction pattern of Mo_2C formed below 650° C shows abnormal relative intensities with (100) stronger than (002), analogous to the abnormal relative intensities reported previously by Jack[18] for the isomorphous ϵ-iron carbide. According to Jack, this anomaly can be satisfactorily accounted for by the needle-like shape of the ϵ-iron carbide, with (101) planes perpendicular to the needle axis.

As mentioned above, Mo_2C is isostructural with ϵ-iron carbide, both having a close-packed hexagonal lattice. Since the precipitation of the latter at about 125° C is known to produce a slight increase in hardness, the precipitation of the former from the same matrix at a higher temperature should also be accompanied by an increase in hardness.

If the secondary hardening is attributed to the precipitation of Mo_2C, it is to be expected that a steel with high carbon and molybdenum contents would show a greater secondary hardening than a steel with a similar Mo : C ratio and a lower carbon content, because the amount of Mo_2C precipitated would be larger in the former than in the latter. Comparing steels *Mo*1 and *Mo*2, it can be seen that the hardness increase in the latter is about twice as large as that in the former. (The decrease in hardness fall between 200° and 450° C is also larger in the latter steel, which definitely cannot be due to the high molybdenum content of the steel, and is probably associated with its high carbon content.)

The acicular appearance of extracted Mo_2C carbide has previously been reported by Fisher,[11] by

Fig. 6—Steel *V*, tempered at 450° C. Acicular cementite, in parallel alignment in the centre ×50,000

Fig. 7—Steel *V*, tempered at 600° C. VC 'threads' and large Fe_3C particles ×150,000

Habraken[7, 8] and by Wever *et al.*,[10, 19] but its change in size and shape with increasing tempering temperature has not been systematically studied. In his investigation of the secondary hardening of Cr–Mo steels, Habraken[7, 8] considered the acicular carbide to be the new iron–molybdenum double carbide M_aC_b previously reported by the present author.[20] However, the interplanar spacings reported by Habraken for the acicular carbide (*loc. cit.*,[7] p. 97) agree very well with those obtained by the present author for Mo_2C in annealed steel specimens:

Habraken's X-phase		*Author's Mo_2C*		
d, Å	Intensity	*hkl*	*d*, Å	Intensity
3·7	—			
3·2	—			
2·52	Medium	100	2·60	Medium
2·29	Weak	002	2·33	Weak
2·20	Very strong	101	2·27	Very strong
1·71	Medium	102	1·73	Medium
1·45	Weak	103	1·47	Medium

The first two reflections of Habraken's X-phase (at $d = 3{\cdot}7$ and $3{\cdot}2$ Å; their relative intensities are not given) probably belong to some other phase.

The sequence in which the carbides appear that are found in tempering medium-molybdenum steels is Fe_3C, Mo_2C ,and M_aC_b, but it usually needs several hundred hours' tempering at 700° C for M_aC_b to appear.[20] Recently Smith[21] at Sheffield University has confirmed the existence of M_aC_b, together with other carbides, in three Cr–Mo steels (0·2% C, 0·8% Cr, 1·0% Mo; 0·2% C, 0·8% Cr, 2·0% Mo; 0·2% C, 1·3% Cr, 1·0% Mo) after tempering at 700° C for 1000 h. His X-ray data on this carbide agree very well with the present author's, which have not been published before and are now presented in Table II. The M_aC_b carbide has not been found in the present two molybdenum steels, probably because of their high molybdenum contents.

The precipitation of W_2C, isostructural with Mo_2C, is known to cause a secondary hardening in high-tungsten steels,[22] and its appearance is expected to be similar to Mo_2C. This carbide has not been investigated, however, because the tungsten dissolved in the matrix is not soluble in HCl or HNO_3, and will precipitate as amorphous tungsten oxides, thus contaminating the extracted carbide. This makes the examination of minute W_2C particles very difficult.

VANADIUM AND TITANIUM STEELS

Houdremont *et al.*[3, 13] have clearly demonstrated that the secondary hardening phenomenon observed in vanadium and titanium steels is due mainly, if not entirely, to the precipitation of VC or TiC, both having the NaCl type of structure. They especially pointed out that these alloy carbides possess a strong resistance to solution treatment, and a very high austenitizing temperature has to be used to obtain the maximum secondary hardening effect.

Koch and Wiester[23] later applied their carbide extraction method to study the tempering resistance of a vanadium steel with 0·3% C and 2·1% V, and they found that for a tempering time of 2 h:

(i) The increase in hardness began at 500° C and reached its maximum at 550° C

(ii) Between 500° and 550° C the iron content of the carbide residue dropped abruptly from about 73% to 21%, and the vanadium content increased correspondingly from 9% to 67%

(iii) Cementite was the only carbide existing at and below 500° C, and VC was the predominant phase

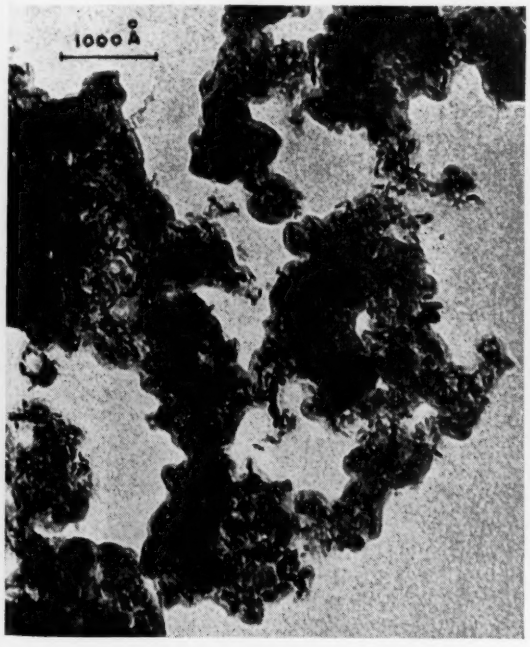

Fig. 8—Steel *V*, tempered at 650° C. Well defined VC 'threads,' indicating increase in thickness ×150,000

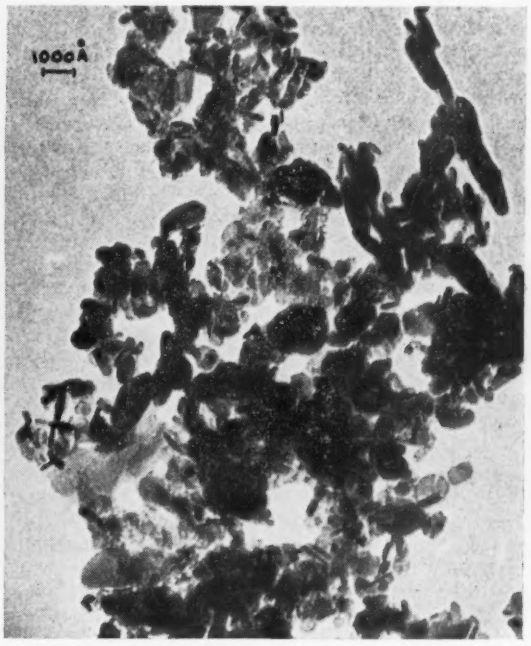

Fig. 9—Steel *V*, tempered at 750° C. VC needles, discs, and spheroids ×150,000

Fig. 10—Steel *Ti*, tempered at 650° C. TiC ' threads ' and large Fe_3C particles ×100,000

(90%) in the residue at 550° C. However, cementite did not disappear completely until 700° C

(iv) The size of VC particles appearing at 600° C is about 200 Å.

According to recent investigations[24, 25] the VC spheroid attains a size of 1000–5000 Å after long temperings at 650–700° C. Moreover, this kind of secondary hardening and carbide conversion also took place in annealing vanadium steels with a bainitic structure, consisting of ferrite and cementite.[24]

Since the original work of Houdremont *et al.*[3] a large number of X-ray and electron diffraction studies has been done in order to ascertain the role played by the precipitation of VC in the secondary hardening phenomenon.[14, 16, 23, 27] However, the appearance of extracted VC carbide has not been examined in detail. What follows is an account of the change in appearance of carbides on tempering a steel with 0·32% C and 1·36% V.

At 450° C only cementite is present, in the form of rods or plates, the length of which is about 1000–2000 Å (Fig. 6). In the centre of this micrograph cementite rods are arranged in parallel alignment, analogous to that previously found by Modin in a eutectoid carbon steel tempered for 1 s at 400° C. The size and shape of cementite found in this steel, and in molybdenum steels as well, do not differ materially from those of cementite in carbon steels. In other words, vanadium has no significant effect on the growth of cementite at 450° C, and the pronounced resistance to tempering imparted to steels by vanadium cannot be due only to the size of the cementite.

Minute VC ' threads ' begin to appear at 525° C, and the amount of this carbide increases with increasing tempering temperature without noticeable growth to 600° C, while cementite disappears correspondingly until it vanishes completely at 650° C. The appearance of VC and cementite at 600° C is shown in Fig. 7, from which it can be seen that the VC ' threads ' are very similar, both in size and shape, to the Mo_2C ' threads ' discussed above (Figs. 1 and 4). The small particle size explains why it is extremely difficult to identify VC by means of X-rays in steel specimens tempered at or below 600° C.

Figure 8 shows the appearance of extracted VC at 650° C. It seems that the length of these VC ' threads ' has increased only slightly, while their contrast has improved and therefore their shape is now much better defined. This indicates that an increase in the thickness of these ' threads ' has taken place between 600° and 650° C.

Further increase in tempering temperature causes the VC ' threads ' to grow into needles, discs, and spheroids, probably successively in this order (Fig. 9). At 750° C, the size of VC particles is still smaller than 500 Å.

The appearance of VC at 750° C has also been studied by the extraction replica method, which shows that at this temperature VC particles appear more often as round discs and spheroids than as

Fig. 11—Formation of a row of uniformly orientated Cr_7C_3 rods from a lamella of cementite in a steel containing 0·43% C and 3·5% Cr (Wever and Koch[31]) ×25,000

Fig. 12—Steel *Cr*, tempered at 500° C. Acicular carbides. X-rays show the presence solely of cementite ×50,000

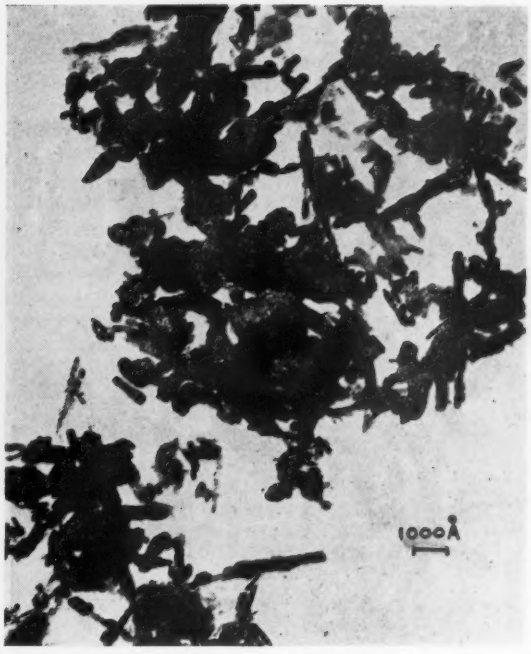

Fig. 13—Steel *Cr*, tempered at 550° C. Acicular carbides. X-rays show the presence solely of cementite ×50,000

needles, and that there is neither a preferred orientation nor a special arrangement, such as in the latter case occurs with the MO_2C carbide (Fig. 3).

From this series of micrographs it becomes obvious that the precipitation of VC during tempering is exactly the same as that of Mo_2C except that:

(i) The growth of VC with increasing tempering temperature is slower than that of Mo_2C
(ii) The tendency of VC to grow into spheroids is stronger than that of Mo_2C.

The similarity in the precipitation behaviour of VC and Mo_2C probably accounts for the resemblance in the hardness/temperature relationship between vanadium and molybdenum steels. The slower rate of growth of VC explains readily the fact observed by Crafts and Lamont[28] that vanadium is more effective than molybdenum in increasing the resistance of a steel to tempering.

Since titanium and vanadium form the same type of carbide as VC, it is to be expected that the presence of titanium, like vanadium, will also cause a secondary hardening. Earlier investigations[3, 4] showed clearly that in this respect titanium, if dissolved in the matrix, is at least as effective as vanadium. However, it should be mentioned that TiC is one of the most difficult carbides to dissolve and therefore the amount of titanium that can be dissolved in austenite is small.

The hardness change of a steel containing 0·50% C and 0·52% Ti with the tempering temperature is shown in Fig. 3. Since the Ti : C ratio of this steel is only about 0·25 (i.e. there is far from enough titanium to combine with all carbon to form TiC), the hardness falls more rapidly and the secondary hardening that occurs in this steel at 550° C is less pronounced than the corresponding phenomenon in the abovementioned molybdenum and vanadium steels.

The change in the appearance of the carbides is more or less the same as that reported above for VC, except that only part of the cementite vanishes at high tempering temperatures to supply the carbon for the formation of TiC, and that the growth of TiC is even more sluggish than that of VC. To avoid unnecessary repetition, only the micrograph showing the coexistence of TiC and Fe_3C at 650° C is printed (Fig. 10). The particle size of cementite in this steel increases continually with raised tempering temperature. The newly precipitated TiC is of about the same size as the Mo_2C and VC 'threads,' i.e. about 30 Å dia. and 200 Å long.

Recently, Cihal and Jezek[29] have shown that in a Ti-stabilized 18–10 Cr–Ni steel, TiC precipitates from austenite as needles, in contrast to the coexisting large triangular blocks of $Cr_{23}C_6$.

CHROMIUM STEEL

As mentioned above, chromium steels exhibit no or only slight secondary hardening and their hardness falls drastically already at 450–500° C, coinciding with the $Fe_3C \rightarrow Cr_7C_3$ transformation. On tempering a 12% Cr steel, Cr_7C_3 was found to be present after 1 h at 525° C.[20] After 4 h tempering at 550° C, this carbide has already attained an average size of 300–500 Å.[30] This possibly explains the small resistance of chromium steels to tempering above 500° C, and the fact that no secondary hardening accompanies the $Fe_3C \rightarrow Cr_7C_3$ conversion.

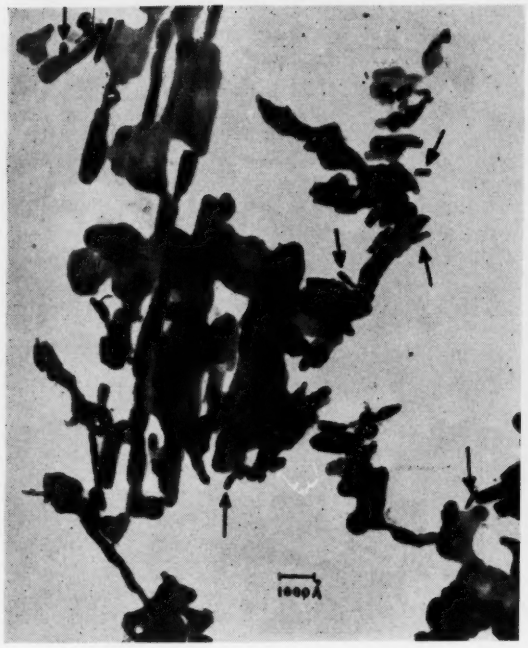

Fig. 14—Steel *Cr*, tempered at 600° C. Small Cr_7C_3 rods (partly marked by arrows) and large cementite particles ×50,000

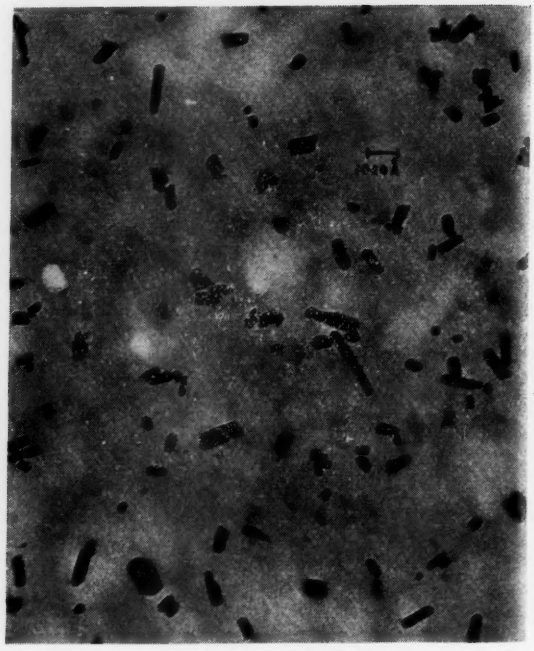

Fig. 15—Steel *Cr*, tempered at 700° C. Extraction replica micrograph showing the random distribution of Cr_7C_3 rods in a martensite (now ferrite) plate ×50,000

The Cr_7C_3 carbide, similar to Mo_2C, also displays, though less distinctly, an acicular appearance. Wever and Koch[31] studied the formation of Cr_7C_3 during and after the isothermal transformation of austenite in a steel with 0·43% C and 3·5% Cr, and supplied the strongest evidence hitherto to prove that Cr_7C_3 forms directly from Fe_3C (or at least starts to form at the cementite/ferrite interface), a suggestion made previously by the present author.[20] Figure 11 is reproduced from their paper, showing short Cr_7C_3 rods, with a uniform orientation, formed at the expense of a cementite lamella. Note that the freshly formed Cr_7C_3 carbide has already attained about 400 Å in diameter and 1200 Å in length. Schrader[32] later supplied further evidence of this transformation mechanism.

The present chromium steel (0·19% C, 2·91% Cr) contains enough chromium to combine with all available carbon to form the Cr_7C_3 carbide, but the $Fe_3C \rightarrow Cr_7C_3$ conversion does not proceed to completion until 650° C, and an X-ray diffraction study fails to detect the presence of Cr_7C_3 at and below 550° C. It was hoped to follow this conversion more closely by means of electron microscopic examination of extracted carbide, in order to find a feasible explanation of the lack of secondary hardening.

Figures 12 and 13 show the appearance of extracted carbide at 500° and 550° C. These micrographs do not show any sign of the non-uniformity in structure characteristic of a mixture of cementite and an alloy carbide, as shown above in molybdenum, vanadium, and titanium steels (Figs. 1, 4, 7, and 10). Therefore it is impossible to ascertain from these micrographs whether Cr_7C_3 exists at these temperatures. Since cementite is the only carbide identified in the X-ray powder photographs, most of the acicular carbide must be cementite. It can therefore be assumed that Cr_7C_3 is either absent or present only in a very small amount with an appearance not differing very much from the coexisting cementite. (Wever and Koch[31] had the advantage of using a large cementite lamella which was easily distinguished from the acicular Cr_7C_3. In tempered martensite cementite also appears in an acicular form, which makes the identification of cementite and Cr_7C_3 in an admixture extremely difficult.)

At 600° C cementite sometimes appears as large plates and Cr_7C_3 as small, short rods (Fig. 14), and consequently these two phases can possibly be identified in a mixture of them. However, the difference in appearance between these two carbides is not always obvious, and the identification of them is sometimes very arbitrary. The Cr_7C_3 particles marked out in Fig. 14 are well defined, with an average diameter of about 200 Å and a length of about 500 Å. In comparison with the minute Mo_2C, VC, or TiC 'threads' (about 30 Å dia. and 200Å long) formed at the same temperature, the Cr_7C_3 carbide is about 3000 times larger in volume.

Above 650° C only Cr_7C_3 exists in this steel, and Fig. 15 is an extraction replica micrograph showing the random distribution of rectangular Cr_7C_3 in a

martensite (now ferrite) plate at 700° C. A similar micrograph has been published previously by Rizol and Utelskii.[9]

This series of micrographs definitely establish these very rapid growth of Cr_7C_3, which makes the differentiation between cementite and this carbide very difficult. It suggests a different mechanism of precipitation from that of other alloy carbides, such as Mo_2C and VC, and this will be discussed in the following section.

Recently, Bungardt and Lennartz[33] have found that during the precipitation of carbides from Ti-stabilized austenitic Cr–Ni steels the $Cr_{23}C_6$ carbide appears at a lower temperature than that for TiC. This may be considered as a parallel observation to that mentioned above.

DISCUSSION

The fourth stage of tempering of alloy steels can perhaps be considered an ageing process occurring in Fe–*M*–C ternary alloys, the precipitate being an alloy carbide containing *M* and carbon (iron does not need to be present, though generally it is) and the rate of ageing being controlled by the diffusion of *M*. According to current theories on precipitation,[34, 35] two sources of lattice straining and therefore hardening are possible: (1) *coherent hardening*—the precipitating phase is coherent with the solid solution from which it later precipitates; and (2) *dispersion hardening*—the precipitating phase consists of very small particles. Geisler[34] maintains that the former is more effective and often occurs in a system with intermediate precipitation stages. The different behaviour on tempering of molybdenum, vanadium, and titanium steels on the one hand and of chromium steels on the other will now be discussed along these lines.

From the description of the appearance of alloy carbides, it is obvious that the minute Mo_2C, VC, and TiC 'threads' precipitating at 500–600° C satisfy the requirement for dispersion hardening, and that their size is comparable with that of a great number of precipitates in aluminium alloys. There is no direct experimental evidence to show that these carbides precipitate coherently from the ferritic matrix, but the following argument may suggest indirectly that Mo_2C possibly does so. On tempering carbon steels, ϵ-iron carbide precipitates before cementite as a metastable phase and the precipitate of this metastable carbide from the ferritic matrix has been considered to be a coherent process.[18] Since Mo_2C is isostructural with ϵ-iron carbide, the precipitation of Mo_2C from the same matrix may also be considered to take place coherently. This, of course, needs to be confirmed experimentally.

The rapid growth of Cr_7C_3 excludes the possibility of dispersion hardening, and the special features of the precipitation of this carbide, as described below, indicate that a coherent precipitation is very improbable.

In a previous paper dealing with the carbide reactions in tempered chromium, molybdenum, and tungsten steels, the present author maintained (*loc. cit.*,[20] p. 373) that "Chromium can replace iron in Fe_3C up to 18%, whereas the solubility of molybdenum or tungsten in Fe_3C is very limited."

"In tempering chromium steels, the concentration of chromium in Fe_3C takes place first, and the transformation of Fe_3C into Cr_7C_3 will not begin until the chromium content of Fe_3C reaches a critical value of about 20%. But by then the chromium content of the ferrite matrix is already very much impoverished. If Cr_7C_3 were formed from the matrix, it should occur more easily in a matrix with a higher chromium content; in other words, immediately after the formation of Fe_3C and before any concentration of chromium in Fe_3C takes place. The experimental results seem to favour the hypothesis that Cr_7C_3 is the transformation product of a reaction of Fe_3C with the matrix....."

"The kinetics of the carbide reactions in molybdenum and tungsten steels are of a different nature from the above-mentioned reaction. The solubility of molybdenum or tungsten in Fe_3C is small; consequently, the molybdenum or tungsten content of the matrix does not change materially after the formation of Fe_3C. On the contrary, the atomic ratio of Mo : C or W : C in the matrix increases considerably, and thus the molybdenum- or tungsten-containing carbide is able to form [directly from the matrix]."

If the point of view that Cr_7C_3 forms by a reaction between the chromium-enriched cementite and the matrix is correct, it is easy to understand why Cr_7C_3 forms incoherently and grows rapidly. (There is already a large region of high concentration of chromium to start with.) As mentioned earlier Wever *et al.* [10, 19] have provided strong experimental evidence (Fig. 11) to support this transformation mechanism.

In the present investigation, only the carbide phase-change has been dealt with, and the change in the matrix has been left entirely untouched. This is only for the sake of convenience, and does not mean that the latter is unimportant. On the contrary, the changes that occur in the matrix affect the hardness of the steel directly, whereas the carbide phase-changes affect it indirectly through their influence on the matrix. However, the changes that the matrix suffers during tempering are very complicated, and are not very well understood even in carbon steels. The most important changes are:

(1) Grain growth and recrystallization of ferrite
(2) Internal strain.

It has been observed earlier in steel *Mo*1 that the orientation of the matrix changes at 650° C, above which large regions of ferrite with nearly uniform orientation appear.[4] However, it has not been ascertained whether this is due to recrystallization or to growth. According to Sata, Nishizawa, and Honda,[36] molybdenum, vanadium, titanium, and chromium all raise the recrystallization temperature and retard the softening of steels during annealing of cold-worked specimens.

On tempering carbon steels, the internal strain decreases gradually. In a vanadium steel containing 0·82% C and 1·07% V, this decrease was found to slow down appreciably at 450–550° C, during which

interval secondary hardening took place.[37] Roberts, Grant, and Cohen[38] observed a slight but distinct increase in electrical resistance in steels containing 4·5% Cr during the fourth stage of tempering, probably indicating a slight increase in internal strain. (However, Crafts and Lamont[16] were unable to find any increase in electrical resistance on tempering high vanadium, molybdenum, and tungsten steels.)

CONCLUSIONS

(1) The appearance of Mo_2C, VC, TiC, and Cr_7C_3 precipitated on tempering molybdenum, vanadium, titanium, and chromium steels have been studied both *in situ* and in the extracted state by means of an electron microscope, and the changes in structure and in hardness, especially the secondary hardening phenomenon, have been correlated.

(2) The carbides Mo_2C, VC, and TiC precipitate at 500° or 525° C in the form of 'threads' about 30 Å dia. and 200 Å long, and their amount increases with increasing tempering temperature at the expense of cementite, which redissolves in the matrix to supply the necessary carbon for the continual precipitation of these alloy carbides. This is accompanied by an increase in hardness, and the maximum hardness commonly occurs at the temperature of the highest rate of precipitation (500–600° C). The growth of these alloy carbides becomes obvious only above 625° C and is most rapid between 650° and 700° C, accompanied by a large fall in hardness. The growth stages are: needles, discs, and spheroids, and the growth rate seems to decrease in the order of Mo_2C, VC and TiC.

(3) The Cr_7C_3 carbide also forms above 550° C, but it grows rapidly to short rods of about 200 Å dia. and 500 Å long, and this possibly explains why chromium steels commonly show no secondary hardening. It is very difficult, and not always possible, to differentiate Cr_7C_3 from Fe_3C particles in tempered chromium steels.

Acknowledgments

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Suction Pyrometers in Theory and Practice

By T. Land, M.A., F.Inst.P., and R. Barber, B.Sc.

SYNOPSIS

Details are given of the precautions necessary to obtain accurate readings with a suction pyrometer. The pyrometer must be designed with an adequate number of radiation shields, and the number necessary under different conditions is shown in the tables and graphs. A high gas velocity is desirable and the means of obtaining it are discussed. In the open-hearth furnace uptake, conventional pyrometers suffer from the effects of overheating and slag attack. Mayorcas and Burton have proposed a pyrometer in which the radiation shield system is enclosed in a water jacket, and this design appears to be the best for such difficult applications. Rigorous methods are described for estimating the error of a pyrometer in use. A pyrometer designed on the basis of the theoretical and experimental work is described and illustrated. 1154

SUCTION PYROMETERS are beginning to be used for routine measurements in steelworks, particularly for measuring the temperature of the preheated air in the uptakes of open-hearth furnaces. There seems to be a need for a clear and simple statement of the basic features which must be incorporated in the design of a suction pyrometer to ensure a given degree of accuracy; there is also a need for simple but rigorous methods of assessing the error of a pyrometer while it is being used. We have recently published[1] a mathematical analysis of the problem of the suction pyrometer together with details of experiments made to test the accuracy of the theory. The purpose of the present paper is to give in a simple form the results of this work, in the hope that it may provide some practical guidance on the measurement of gas temperatures in steelworks.

It is not easy to measure the temperature of the hot gas, particularly if its surroundings are at a very different temperature. A sheathed thermocouple, placed in the gas, takes up a temperature much nearer to the temperature of the surrounding surfaces than to that of the gas. This is because, at high temperatures, the radiant heat-transfer coefficient between the thermocouple and its surroundings is so much larger than the convective heat-transfer coefficient between the thermocouple and the gas. To measure the true gas temperature, the thermocouple must be isolated very carefully from radiation received from the brickwork, usually by surrounding the thermocouple with a series of concentric radiation shields. At the same time the convective heat transfer to the thermocouple is greatly increased by sucking the hot gas past the thermocouple and the radiation shields at a high velocity. In this way, it is possible to reduce the effect of the radiant heat from the brickwork to negligible proportions, and to ensure that the pyrometer measures the true temperature of the hot gas.

In theory this sounds simple and straightforward, but in a practical case how should a pyrometer be designed for a particular application? How many radiation shields will be necessary and what gas velocity should be used? There is no great difficulty in making a pyrometer which gives a reading of some kind, but the problem of designing a pyrometer to give a specified performance is not particularly easy. Little help is available from text books, and the British Standard Code for Temperature Measurement is noticeably reticent. It is hoped that the principles set out in the present paper may give useful and practical guidance on the design of suction pyrometers.

Table I

EFFICIENCY (%) FOR SHEATHED THERMOCOUPLES WITH MULTIPLE RADIATION SHIELDS OF BLACKENED METAL

Gas velocity 500 ft/s

Temperature, °C	Number of Radiation Shields									
	1	2	3	4	5	6	7	8	9	10
400	98									
600	88	98								
800	71	93	98							
1000	54	81	93	97	99					
1200	39	69	85	92	95	98	99			
1400	28	55	74	83	91	95	97	99	99	
1600	20	43	62	73	83	90	94	96	97	98

DESIGN AND EFFICIENCY

The accuracy of a suction pyrometer depends on the difference in temperature between the gas and the surroundings of the pyrometer. For this reason it is not possible to state the accuracy of a pyrometer of conventional design as 'so many degrees Centigrade.' If no gas is sucked past the thermocouple and the radiation shields the pyrometer will have a certain error; when gas is aspirated past the couple and shields a certain fraction of this error will be eliminated; we will call this fraction 'the efficiency of the pyrometer.' This concept of 'efficiency' is of fundamental importance to the accuracy of suction pyrometers. If the conditions at the point of measurement are such that a simple sheathed thermocouple registers a temperature within 25° C of the true gas temperature, then a suction pyrometer with an efficiency of only 80% would reduce the error to 5° C; but if conditions were such that the error of

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Mr. Barber is in the Research Department of Land Pyrometers Ltd., Sheffield, of which Mr. Land is Managing Director.

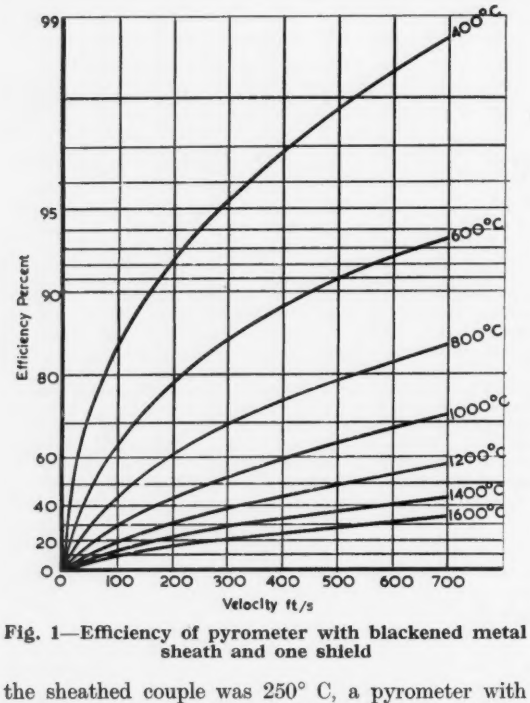

Fig. 1—Efficiency of pyrometer with blackened metal sheath and one shield

the sheathed couple was 250° C, a pyrometer with an efficiency of 98% would be necessary to obtain the same absolute accuracy.

In designing a suction pyrometer the first question to decide is how many radiation shields will be needed. The number of radiation shields depends mainly upon the temperature at which the pyrometer is operating. The efficiency of a sheathed thermocouple with one radiation shield at different gas velocities and different temperatures is shown in Fig. 1. The curves have been drawn on the assumption that the pyrometer sheath and the radiation shields are all of oxidized metal having a high emissivity and a high thermal conductivity. It will be seen that a simple pyrometer of this kind is useful only at temperatures up to about 500° C. When two concentric radiation shields are placed around the sheathed thermocouple the efficiency is considerably improved, as Fig. 2 shows, and such a pyrometer will give accurate results up to about 800° C. At higher temperatures it is necessary to use large numbers of radiation shields and the efficiency of pyrometers with multiple shields is shown in Table I. It is clear that four or five simple radiation shields are desirable at 1000° C and five or six shields at 1200° C. This result fully agrees with Marsh[2] who found it necessary to use a suction pyrometer with five concentric nickel radiation shields to measure the temperature of the preheated air in an open-hearth furnace.

Table I is calculated for a gas velocity through the radiation shield system of 500 ft/s. If the gas velocity is less than 500 ft/s the pyrometer will operate less efficiently and as if it had a smaller number of radiation shields. This is indicated in Table II, from which it will be seen that if the gas velocity were 100 ft/s the pyrometer would have only the same efficiency as one with only half the number of radiation shields operating at the full velocity of 500 ft/s.

These tables and graphs summarize the results of numerous calculations and experiments, and the inevitable conclusion is that it is relatively easy to measure gas temperatures of 500° or 600° C, but at 1000° C a pyrometer of some complexity is needed, using multiple radiation shields and a high gas velocity. This fact has usually been understood by those who have measured gas temperatures in the open-hearth furnace, but it may be worth emphasizing once again now that suction pyrometers are beginning to be used more widely in the steel industry.

Refractory radiation shields are necessary at high temperatures and although they are fragile and require fairly frequent replacement they have the compensating advantage that clean refractory surfaces have lower emissivities than most oxidized metals. As a result, it has been shown both in theory and in practice that each refractory radiation shield when new and clean may be equivalent to two or even three oxidized metal shields, and pyrometers with only two refractory shields have been used with fair efficiency in open-hearth uptakes. It is important to remember that this efficiency depends greatly on the low value of the emissivity of the refractory surfaces; after a period of use the surfaces may become contaminated and the emissivity may rise, and if this happens the efficiency may be seriously impaired. Refractory radiation shields must therefore be used with caution.

BARE THERMOCOUPLES AND COMPLEX RADIATION SHIELDS

In some applications the bare thermocouple wires may be exposed to the gas in the radiation shields.

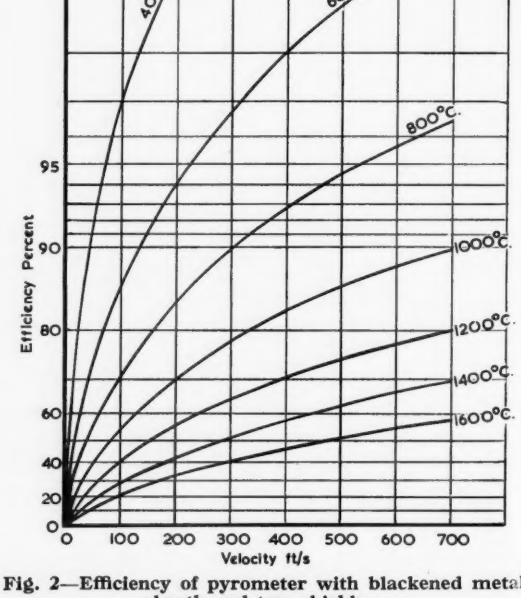

Fig. 2—Efficiency of pyrometer with blackened metal sheath and two shields

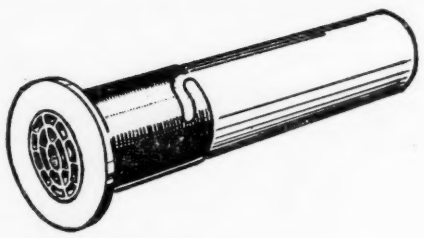

Fig. 3—Type 4*B* refractory hood

If the gas velocity is no more than 100 ft/s the use of a bare base-metal thermocouple does not greatly improve the efficiency of the pyrometer, but at 500 ft/s it may be equivalent to adding an extra radiation shield to the system. Occasionally, the gas is clean enough for a bare platinum thermocouple to be used and the error of the pyrometer may then be reduced by a factor between 5 and 10. Unless the air is very clean the surface of the wire soon loses its brightness, and the emissivity rises, making the pyrometer less efficient. It cannot be expected that a pyrometer with a bare thermocouple will prove satisfactory in open-hearth furnace applications except for brief periods of operation when such a pyrometer may be used as a standard.

So far only simple concentric radiation shields have been considered. It is often an advantage to use more complex systems; if a sufficient number of fins is fitted to each cylindrical shield the convective heat transfer is improved and each finned shield may be equivalent to $1\frac{1}{2}$ simple shields. With metal shields care must be taken to avoid thermal contact between successive shields when fins are used. Schack[3] showed that a ring of small refractory tubes formed a very efficient radiation shield, and it can be shown that each ring of small tubes may be equivalent to at least two simple radiation shields as long as the gas can pass freely all round the small tubes. The high thermal conductivity of metals makes this system unsatisfactory in metal. Extruded refractory radiation shields of special section have been most satisfactory.

Mayorcas and Burton[4] have found that a multiple refractory radiation shield enclosed in a water-cooled jacket provides an excellent means of measuring the temperature of preheated air in an open-hearth furnace. The primary advantage of enclosing the refractory system in a water-cooled housing is that it protects the outer surface of the refractory, which otherwise becomes very hot, and may be attacked by drips from the roof or by slag particles during the waste-gas part of the cycle.

Table II

EFFECT OF USING GAS VELOCITIES OTHER THAN 500 ft/s IN SUCTION PYROMETERS WITH MULTIPLE RADIATION SHIELDS

Velocity, ft/s	10	20	50	100	200	300	400	500	600	700
Equivalent number of shields at 500ft/s	0·21	0·28	0·40	0·52	0·69	0·82	0·93	1·00	1·07	1·14

It is evident from the limited number of tests carried out so far that this design of pyrometer has great possibilites, especially in the measurement of preheated air temperatures. The extruded hood illustrated in Fig. 3 has given results which seem to be accurate and dependable. Further experiments are being made by B.I.S.R.A. to determine whether an extra radiation shield might be desirable at temperatures approaching 1400° C. (An account of this work is to be published.) It should be noted that Tables I and II cannot be applied directly to pyrometers of this type.

When the radiation shield system is enclosed in a water-cooled jacket, the temperature of the surroundings differs far more from the temperature of the gas than it would if the radiation shields were exposed in the uptake. It might be inferred that the pyrometer would operate much less accurately with the radiation shields in the water-cooled housing but this is not so. Experiments confirm that the lower average temperature of the refractory radiation shields compensates for the larger temperature difference between gas and surroundings, and it is found in practice that the same radiation shield operates with about the same accuracy whether it is enclosed in a water jacket or exposed to the hot surroundings in an uptake. When the radiation shield system is withdrawn into the water jacket its life is greatly extended and the instrument becomes far more robust and reliable.

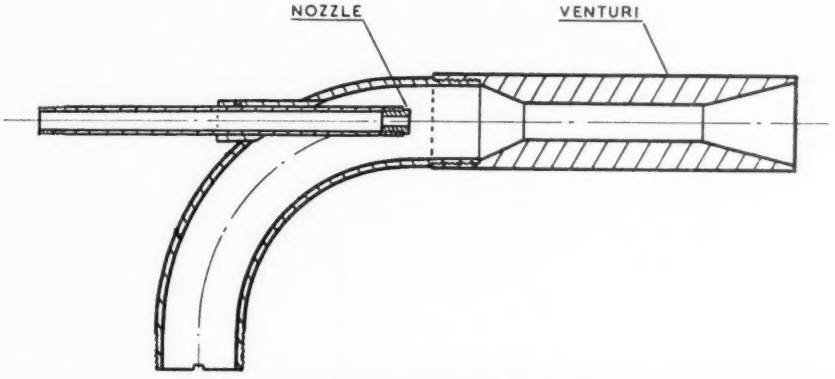

Fig. 4—Compressed air or steam ejector

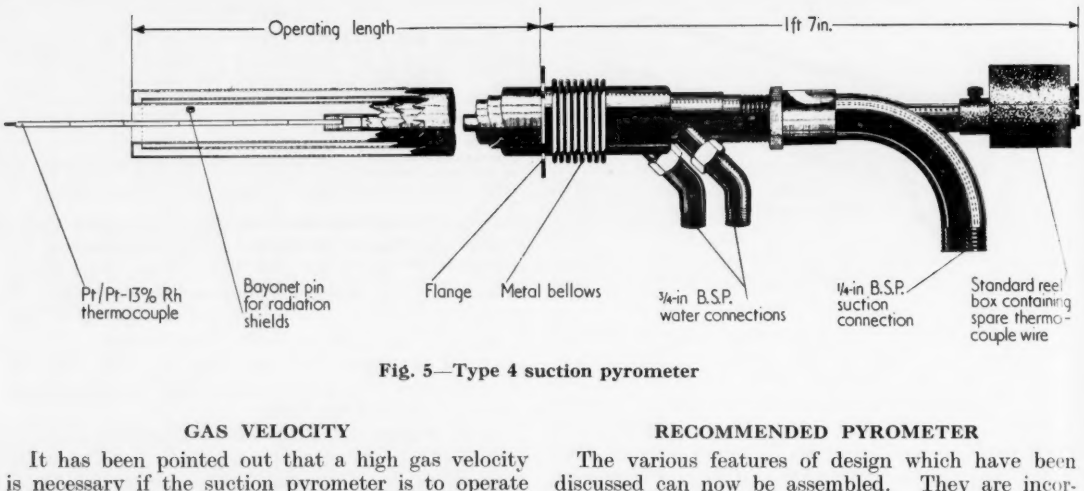

Fig. 5—Type 4 suction pyrometer

GAS VELOCITY

It has been pointed out that a high gas velocity is necessary if the suction pyrometer is to operate efficiently, but there is a limit to the velocity which should be used. When slowly moving gas is accelerated to a high velocity its kinetic energy is obtained at the expense of its thermal energy and the gas is cooled. When the moving gas comes in contact with the thermocouple tube it gives up part of its kinetic energy on impact, but a certain degree of cooling still remains. The error introduced in this way becomes of practical significance at velocities around 700 ft/s and it is unwise to use velocities much greater than 500 ft/s.

Fortunately, the theoretically desirable limit of velocity cannot be exceeded easily with the types of fans and ejectors usually available. To obtain a velocity of 500 ft/s through the radiation shield system great care must be taken with the design of the whole pyrometer, avoiding all restrictions and sharp bends. The gas should be led away in straight or gently curving pipes of adequate diameter. In some applications a fan is most convenient as only electric power is required. The gas must be adequately cooled before it reaches the fan, and this is done by providing a water-cooled section in the pyrometer. As a rough guide, it may be said that a water-cooled tube a hundred diameters long should be adequate to cool the gas from 1000° C.

In many industrial applications compressed air or steam is readily available and in such cases an ejector is a convenient means of aspirating the gases. Some ejectors described in the literature require the gas to pass round sharp bends. It has been found more efficient, and incidentally much less noisy, to use a more ' streamline ' construction such as that in Fig. 4.

It is better to measure the mass flow of gas rather than the suction; it is then possible to deduce the velocity of the hot gases in the radiation shield system. The flow of the gas can be determined conveniently by using a Venturi and differential pressure meter. If the gas flow in pounds per hour is divided by the cross-sectional area of the radiation shield system in square inches, then the velocity of the hot gas may be found at once by referring to Table III.

RECOMMENDED PYROMETER

The various features of design which have been discussed can now be assembled. They are incorporated in a pyrometer, now commercially available, which was designed for use in power stations, steel-melting and other large furnaces, and glass tanks. The pyrometer (*see* Fig. 5) can be used with the radiation shields either fitted externally in the conventional manner or enclosed in the water jacket. It comprises a water-cooled probe of stainless steel usually 6 ft long, to which can be attached standard elements, such as a Venturi and meter to measure the flow of gas and either an ejector of the design shown in Fig. 4 or a fan. The thermocouple is of platinum and platinum–13% rhodium wires with a reserve of wire retained in a reel box of the type widely used in liquid steel immersion pyrometers. Either a finned Inconel sheath or a refractory sheath may be fitted to cover the portion of the thermocouple within the radiation shield system. The radiation shield is attached to the water-cooled probe by means of an internal bayonet fitting and three types of shield can be used. A shield consisting of four finned Inconel tubes is used for temperatures up to 1150° C. For temperature measurement of preheated air in the uptakes of open-hearth furnaces a special extruded refractory hood (Fig. 3) has been designed to fit inside the water-cooled probe. For some high-temperature applications a double refractory radiation shield outside the water-cooled probe is most suitable and this can be fitted when required; alternatively, the extruded hood can be used externally. The features of the pyrometer are its adaptability to

Table III

MASS FLOW OF AIR, lb/h per in²

Temp., °C	Velocity, ft/s								
	100	200	300	400	500	600	700	800	900
200	116	232	348	464	580	696	812	928	1043
400	84	168	252	335	419	503	587	670	755
600	63	126	188	251	314	377	440	502	565
800	51	102	153	204	255	306	357	408	460
1000	43	86	129	172	215	258	301	344	387
1200	37	74	112	149	186	223	260	298	335
1400	33	66	98	131	164	197	230	262	295
1600	29	59	88	117	146	176	205	234	264

a wide variety of conditions, the ease with which the radiation shield can be renewed, and the streamlined layout of the gas flow system which allows a high gas velocity to be attained.

ESTIMATING ACCURACY IN USE

When a suction pyrometer has been made and put into operation it is important to find out how accurately it is measuring the true temperature of the gas. The usual method is to take readings over a wide range of velocities and to plot a curve relating the indicated temperature to either gas velocity or suction. If the curve appears to flatten off at the operating velocity, the pyrometer is considered to be operating efficiently. In this simple form the test is of a qualitative character, but we have shown in our mathematical analysis of the problem that the shape of the temperature velocity curve can be used in a quantitative way to assess the accuracy of the readings obtained. We have also been able to indicate another way of estimating the accuracy of readings. The suction is turned on and the pyrometer is left to record the temperature until a steady value is obtained; the suction is then turned off and a second curve is recorded. The ratio of the time constants of the heating and cooling curves obtained in this way gives a quantitative estimate of the accuracy of the pyrometer.

In the most careful work on pyrometers using radiation shields fitted outside the water jacket this type of method is recommended, but there is a simple test which is adequate for many purposes. In an efficiently designed suction pyrometer the error of measurement happens to be approximately inversely proportional to the gas velocity over the higher range of velocities. The following procedure is therefore recommended. The suction is turned full on when the pyrometer is in its opening position, and the drop in temperature is noted; the velocity is then reduced by half and the temperature is observed. If the pyrometer is operating accurately, the drop in temperature when full suction is applied will be at least ten times as great as the rise in temperature when the gas velocity is halved; and this rise in temperature will be approximately equal to the error of the pyrometer operating at maximum velocity. If the ratio is much less than ten then the error will exceed the rise in temperature and may exceed it by a large factor if the ratio is less than seven. When the suction is turned off, the outlet from the pyrometer must be efficiently stopped up, otherwise hot gas or cold air may be drawn through the radiation shields by the positive or negative pressure in the furnace, relative to the atmosphere, thus giving misleading readings.

In preheated air measurement in the open-hearth furnace the drop in temperature when the suction is turned on will usually average between 100° and 250° C. We may therefore say simply that the pyrometer is operating accurately if the temperature rises by no more than 10° C when the gas velocity is halved. If the air preheat is unusually high, Cashmore[6] has shown that the temperature drop when the suction is turned on may be as little as 50° C; it is then advisable to insist that the temperature should not rise by more than 5° C when the gas velocity is halved.

The type of pyrometer in which the radiation shields are enclosed in the water jacket seems likely to be widely used. The same method of testing is recommended as the best available; the gas velocity should be halved and the change in reading will give a good estimate of the error at full velocity.

CONCLUSIONS

A suction pyrometer needs careful design and intelligent use. It is essential to provide an adequate number of radiation shields around the thermocouple, and a pyrometer with a single radiation shield is quite useless at 1000° C. In the uptake of an open-hearth furnace, a pyrometer with five metal radiation shields or three refractory shields will give accurate readings, but both may suffer from overheating or slag attack during the waste-gas cycle. The best solution appears to be the use of an extruded refractory hood in a water-cooled jacket, as proposed by Mayorcas and Burton. A rigorous method of checking the pyrometer in use is necessary and the simple method described should be adequate and convenient for routine work. If these precautions are observed, suction pyrometers can be used with confidence in any steelworks.

Acknowledgments

We wish to acknowledge the co-operation we have received from many friends in different industries who have provided facilities for the experimental work, including the British Iron and Steel Research Association, Steel Peech and Tozer, Ltd., Pilkington Bros., Ltd., Central Electrical Authority (N.W. Division), and the British Coal Utilisation Research Association. The work as it progressed has been discussed with members of the Pyrometry Sub-Committee and of the Steelmaking Instruments Sub-Committee of B.I.S.R.A. and with the staff of B.C.U.R.A.

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An X-Ray Examination of Preferred Orientation and the Transformation $\gamma \rightarrow \alpha$ in a Stainless-Steel Wire

By K. W. Andrews

SYNOPSIS

Austenitic stainless-steel wire of the 18/8 Cr–Ni type possesses a preferred orientation in which a diagonal of the face-centred cube lies parallel to the wire axis. This ⟨111⟩ orientation is formed in the drawn wire and persists through several stages of annealing and drawing. A minor component in the orientation is represented by a cube edge ⟨100⟩ lying parallel to the wire axis. Other X-ray effects are explained by the existence of twinned crystals. The austenite also undergoes transformation to ferrite on cold drawing. The maximum amount of ferrite depends on the composition, but also increases towards the centre of the wire. The orientation of the ferrite phase can be interpreted by considering its dependence on the austenite phase according to a crystallographic relationship between the two lattices. The relationship which gives the most satisfactory agreement is that of Nishiyama. 1182

Introduction

IT IS WELL KNOWN that the austenite phase in many chromium–nickel stainless steels, especially of the '18–8' type, is metastable and is liable to undergo partial or even complete transformation to the ferrite phase on the application of cold work. The fact that this transformation could be brought about by cold deformation was probably first discovered by Aborn and Bain.[1] A recent study of the effects of cold work on alloys in the range 18–25% Cr and 8–12% Ni has been described by Cina.[2] In Cina's work transformation was induced either by compression or tension. Hobson, Chatt, and Osmond[3] described an investigation into the properties of stainless-steel wire in which the ferrite had been produced during the wire-drawing process where the stress system is more complicated than either simple tension or compression. Drawn stainless wire of this kind has been used for magnetic sound recording and in this instance the authors attempted to describe the orientation of the ferrite particles by studying the magnetic properties. Further aspects were mentioned in the discussion of the paper.[4]

A more general effect of plastic deformation on metals is the establishment of preferred orientations or deformation textures.[5, 6] In the case of cold-rolled or cold-drawn stainless steel, there are two phenomena which must be considered: the tendency to develop a preferred orientation, and the tendency for the simultaneous transformation of austenite to ferrite. Although a considerable amount of work has been reported on the texture of body-centred cubic iron or steel, there appears to be very little on the texture of the face-centred cubic austenite, apart from some preliminary results noted in the discussion referred to.[4] Neerfeld and Mathieu[7, 8] however, used the orientation effects in the parent austenitic γ phase and the ferritic α phase produced by deformation in tension to postulate an orientation relationship between the two phases, and from this relationship a mechanism for the transformation. A somewhat similar approach has been used in the interpretation of some of the results in the present paper. However, the conditions of plastic deformation in the production of wire are different from the simple deformation in tension used by Neerfeld and Mathieu. This difference might be responsible for any difference in conclusions. Certain criticisms can also be made in connection with their X-ray experimental technique. These will be referred to later.

The present paper describes briefly the industrial processes through which the wire passes, and the structure at these different stages. The texture of the austenite phase is described. The preferred orientation of the ferrite phase requires a more complex treatment involving a consideration of possible relationships between the crystal lattices.

EXPERIMENTAL WORK

Materials

Stainless-steel wires of two different compositions were used. Their chemical analyses (principal elements) are given in Table I.

The more detailed study of the effects of the different stages of drawing and annealing was confined to steel *A*. The austenite in this steel was more stable and in practice only underwent transformation up to 15–20% ferrite. The lower C and Ni content of steel *B*, however, resulted in a considerably less stable austenite and the hard-drawn wire showed a much higher proportion of ferrite.

Samples of wire *A* were taken at stages during the course of production in the Rotherfield works of Samuel Fox and Co., Ltd. Wire *B* was obtained in the hard-drawn condition only. Some details of the production process are given in the presentation of results (Table II).

X-ray Examination

X-ray photographs were taken in a standard single-crystal camera generally employing a cylindrical film holder of 6 cm dia., although a flat film cassette was also available. Cobalt radiation was used except in certain critical cases where molybdenum radiation was employed for confirmation and to obtain more complete diffraction rings.

Previous work in the laboratory[4] had shown that the amount of ferrite formed from austenite increased from the outside of a wire towards the centre, so that although the surface layers might be almost completely austenitic, the centre could contain a considerable proportion of ferrite. In the present study therefore, wires were examined on the surface and then selected wires were examined after removal of successive layers by electrolytic solution. The possible effect of nitrogen on the difference in the amounts of ferrite between the centre and the outside of a wire is considered in Appendix II.

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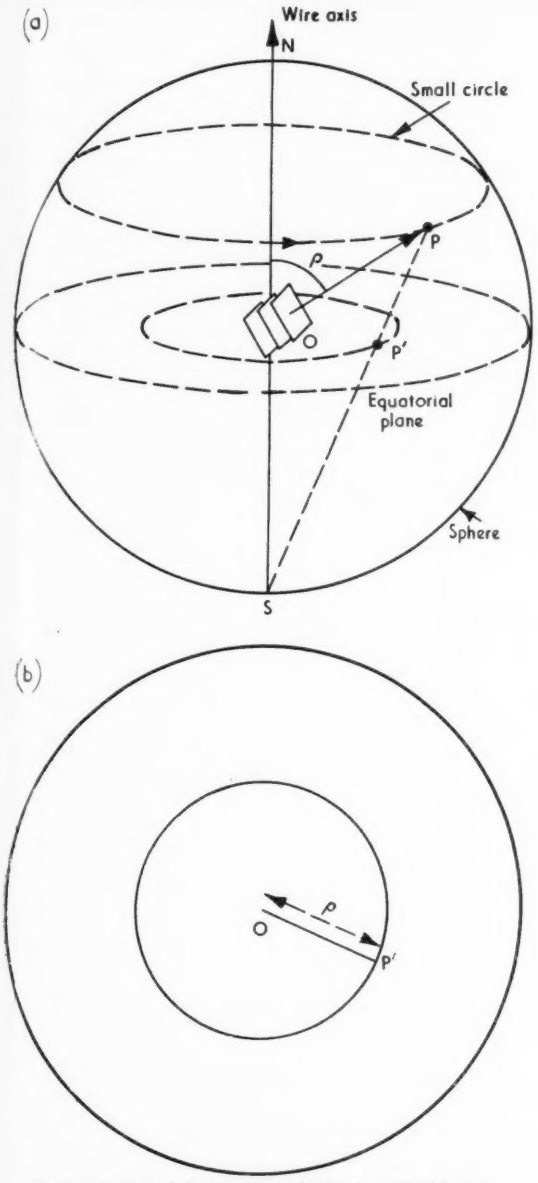
The author is with the United Steel Companies, Ltd., Research and Development Department.



(*a*) Construction of stereographic projection in equatorial plane
(*b*) Stereogram or pole figure for chosen set of crystal planes at centre of sphere O

Fig. 1—Description of orientation

Table I

CHEMICAL ANALYSES OF STAINLESS STEEL WIRES

Steel	C, %	Mn, %	Si, %	Ni, %	Cr, %
A	0·10	0·63	0·55	9·80	19·16
B	0·062	0·51	0·6	8·11	18·1

The nitrogen contents of these steels are reported separately in Appendix II

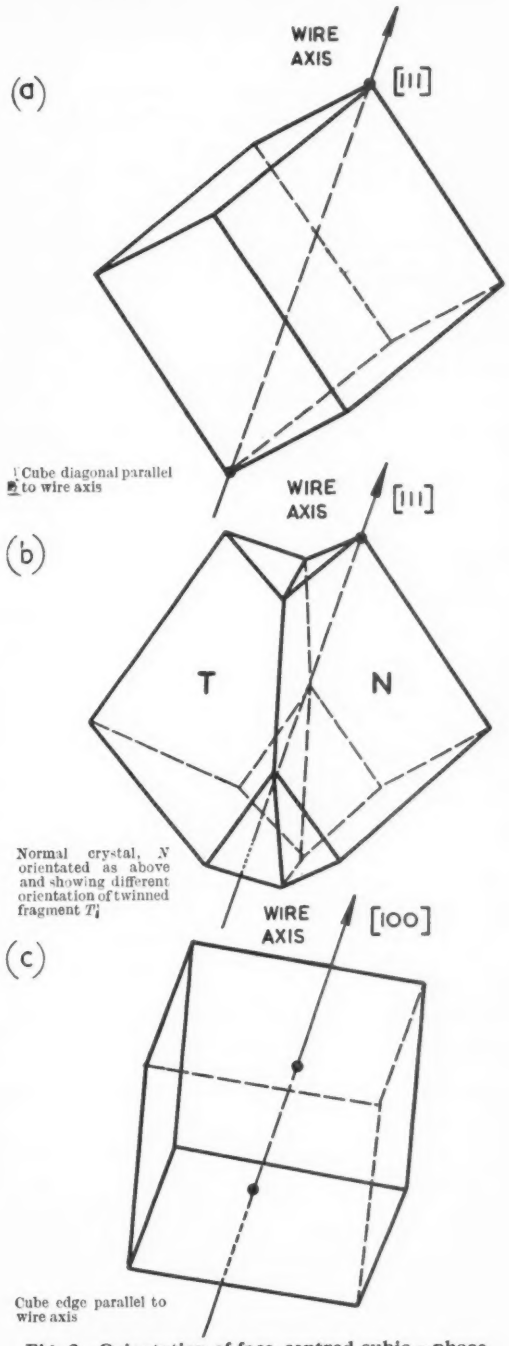


Fig. 2—Orientation of face-centred cubic γ phase

The interpretation of the X-ray films was carried out in the usual way and with the assistance of standard charts giving the angle ρ in Fig. 1. In Fig. 1*a* OP is perpendicular to a set of planes and ρ is the angle between OP and the wire axis. Since there is symmetry about the wire axis, which usually coincides with a crystallographic direction of simple indices,

Table II
X-RAY PHOTOGRAPHS OF WIRES (STEEL *A*)

Condition	Diameter	Radiation	Orientation of γ Phase	Amount of α Phase
Annealed—as supplied	0·080 in. etched to 0·058 in.	CoK_α	Very little preferred orientation	Nil
Hard drawn to 0·036 in. dia. (from 0·080 in.)	Outside of wire 0·036 in.	CoK_α	[111] and some [100]. Twin crystal reflections present. (Somewhat obscured by contribution of [100])	Nil
	Etched to 0·032 in.	CoK_α	As above but [100] slightly less pronounced with effect of twin crystals. (Slightly sharper)	~10%
	Etcheddown to 0·013 in.	CoK_α	Similar to above	~15%
	Etcheddown to 0·004 in.	CoK_α	Similar to above	~15%
		MoK_α	More definite confirmation of the effects by extra peaks and diffraction rings	
Bright-annealed 1050° C and light drawn to 0·032 in. dia.	Outside of wire 0·032 in.	CoK_α	Slight orientation only	Nil
	Etched to 0·0235 in.	CoK_α	Orientation sharper but not as sharp as for hard-drawn wire. Also twin effect less pronounced and [100] more	None detected
Hard drawn to 0·0136 in. dia. from 0·032 in.	Outside of wire 0·0136 in.	CoK_α	Orientation similar to above for 0·032 in. wire (but only a surface effect)	Nil
	Etched to 0·0115 in.	CoK_α*	Orientation much sharper [100] present but less pronounced than at 0·032 in. dia.	Not detected
	Etched to 0·008 in.	CoK_α	As above	Very small, about 5%
	Etched to 0·004 in.	CoK_α	Similar to above	5–10%
		Mo$K_{\alpha,\beta}$	General confirmation	
		MoK_α	Further confirmation (more detail)	
Bright-annealed at 1050° C at 0·0136 in. dia.	Outside of wire 0·0136 in.	CoK_α	[111] orientation + twin effect but less marked in view of stronger [100] orientation. Moderately developed	Nil
	Etched to 0·008 in.	CoK_α	Orientation considerably sharper and [100] much less marked	Nil
	Etched to 0·0045 in.	CoK_α	As above. Practically no [100] but twin effect clear	Nil
		Ni$K_{\alpha,\beta}$	General confirmation	
		Mo$K_{\alpha,\beta}$	" " (fuller details)	
		MoK_α	General confirmation (fuller details)	
	Etched to 0·002 in.	CoK_α	Predominantly [111] + twin effect. (Small amount of [100] possible)	Nil
Hard drawn to 0·004 in. dia., from 0·0136 in.	0·004 in. (surface layers to depth of 0·001 in. or less)	CoK_α	[111] with twinned crystals + [100] (more marked than for annealed wires)	5–10%

*2 photographs: (*a*) Specimen vertical, (*b*) Specimen tilted 60° with vertical
Also special photograph with Mo$K\alpha$ radiation of hard-drawn steel *B* (see p. 281)

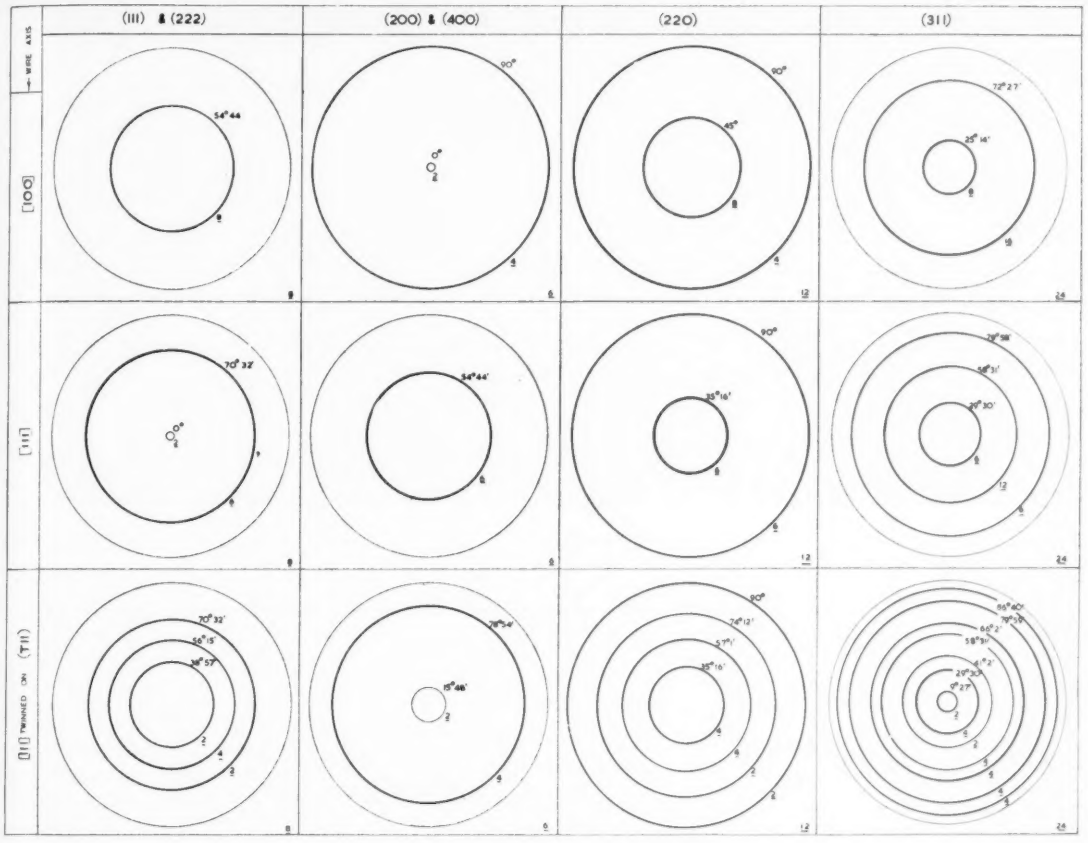


Fig. 3—Ideal pole figures for γ phase

it is only necessary to derive possible values of this angle for different sets of planes. If desired, a stereographic projection may be drawn as in Fig. 1*b*. Values of the angle ρ between planes and directions for cubic crystals were originally tabulated by Bozorth, but the table contained some errors and has since been revised and considerably extended.[10]

RESULTS AND INTERPRETATION

General

Table II describes the structure of wire *A* as obtained at different stages of the production process. The orientation of the γ austenite phase is described in words. That of the α phase could not be fully established from these photographs and hence the need for confirmation from a steel giving a higher proportion of ferrite. Some X-ray photographs are shown in Figs. 5–8.

Table II shows that there is general confirmation of the formation of ferrite in larger amounts towards the centre of drawn wires, and of the existence of a layer of untransformed austenite at the surface. The orientation of the austenite phase when once established by the hard-drawing process is not removed by the industrial annealing process as ordinarily used in the works. The annealing treatments cause any ferrite formed to retransform, but the austenite phase retains its orientation. This orientation contains some interesting features which will now be described.

Orientation of the Face-centred Cubic Austenite Phase

The predominant orientation of the austenite is that in which a cube diagonal lies parallel to the wire axis, often described as a ⟨111⟩ texture. There is also evidence that a small proportion of crystals have a cube edge parallel to the wire axis described as a ⟨100⟩ texture. These two textures are typical of face-centred cubic metals, but the proportions of the two may vary considerably. Thus Barrett[6] (Table XIX) reports that aluminium shows only the ⟨111⟩ texture whilst silver shows only 25% of this texture and 75% of the cube edge texture. In the case of stainless steel the behaviour is near to that of aluminium, and the proportion of crystals with the ⟨100⟩ orientation is small. This ⟨100⟩ component is slightly more pronounced at the surface of the wire and tends to get less towards the centre. It is also clear that the ⟨111⟩ orientation in general is not as sharp on the outside of the wire, but becomes more pronounced towards the centre. No evidence of a 'zonal texture'[5] was obtained, nor were there any diffraction effects which might derive from an existence of a ⟨112⟩ texture in the outer layers, such as was noted by Bastien and Pokorny[11, 12] for copper or copper alloys.

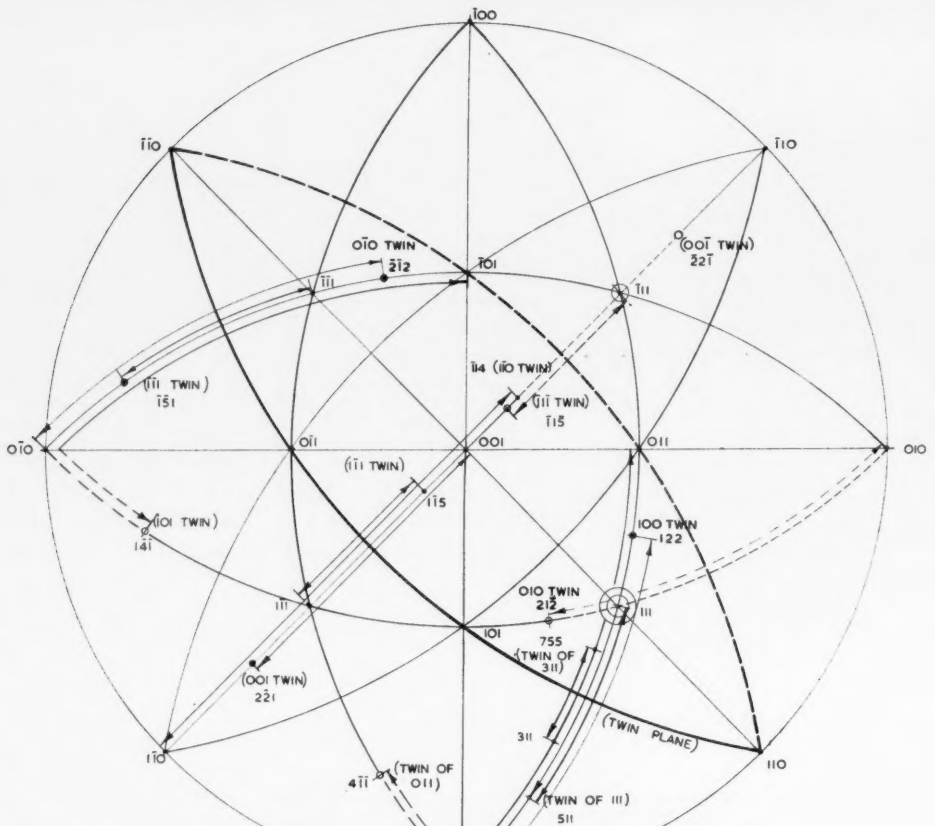


Fig. 4—Stereographic projection of cubic crystal showing effect of twinning on (1̄11) plane (note position of [111] and [1̄11] poles)

An additional interesting feature of the orientation arises from the existence of face-centred cubic twins. These are quite typical of metals with this structure and exist in the annealed wire as originally received. Further drawing does not appear to eliminate the twins, although they are only clearly delineated under the microscope in the wires when in the annealed condition. It will be apparent from crystallographic considerations that both the parent crystal and a twin band cannot have the same orientation. The situation may be represented by Fig. 2 where the simple ⟨111⟩ texture is illustrated first. Figure 2*b* shows a twinned crystal in which the normal or parent crystal (*N*) is correctly oriented. The twinned fragment (*T*) has a different orientation. Figure 2*c* shows the cube edge ⟨100⟩ orientation.

A microscopical examination shows that the proportion of metal corresponding to *T* in Fig. 2*b* is not very large. Some grains are twinned on planes of the ⟨111⟩ type perpendicular to the wire axis. Extra X-ray diffraction effects can only arise from twins on planes of the ⟨111⟩ type at an angle to the wire axis. Ideal pole figures are shown in Fig. 3, and correspond to the three orientations in Fig. 2. The centre row for [111] corresponds to the strongest observed peaks. The bottom row of pole figures corresponds to twins on a (1̄11) plane when (111) is perpendicular to the wire axis.

To derive the extra angles for the pole figures in this last row of Fig. 2, it is necessary to find the indices of crystallographic planes in the parent crystal (*N* in Fig. 2*b*) to which the diffracting plane in the twin (*T* in Fig. 2*b*) is parallel. This can be done with the aid of transformation formulae described elsewhere.[13] The planes and relevant angles corresponding to the first six diffraction lines for face-centred cubic metals are given in Table III. To complete the description, it may be useful to refer to the stereographic projection in Fig. 4. The direction representing the wire axis [111] is surrounded by a double ring, and the normal to the twin plane [1̄11] by a single ring. The twin plane is given by the two thicker arcs which are projections of a great circle. Some of the transformations of indices are illustrated in this diagram.

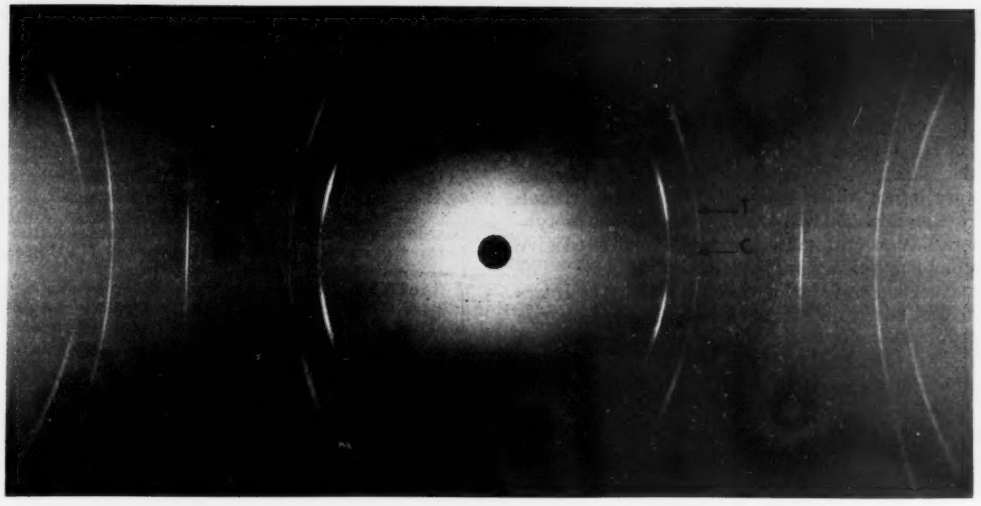


Fig. 5—X-ray photograph of region near centre of annealed wire, steel *A*, 0·0136 in. dia. CoK_α radiation. *C* = intensity due to cube-edge ⟨100⟩ orientation, *T* = intensity due to twinned crystals

The diffraction effects due to the twinned fragments are necessarily rather weak and are comparable with those due to the ⟨100⟩ orientation. Figures 5–7 show X-ray patterns of the austenite phase. Some of the diffraction maxima which arise from the twinned crystals and the ⟨100⟩ crystals are pointed out. The photograph with molybdenum radiation illustrates the value of using this radiation to give more complete rings and hence to enable a fuller check of the orientation.

Amounts and Orientation of the Ferrite Phase

The orientation of the ferrite phase in steel *A* could not be established fully as the amounts were too small. Steel *B*, however, gave a much greater proportion of ferrite towards the centre of the wire, and was used to establish the nature of the orientation. The proportions of ferrite in this wire at different depths from the surface were as follows:

Dia., in.	Amount of γ	Amount of α
0·055	Large	Small
0·040	Small	Large
0·030	Very small	Very large
0·020	None detected	,,
0·012	,, ,,	,,
0·007	,, ,,	,,

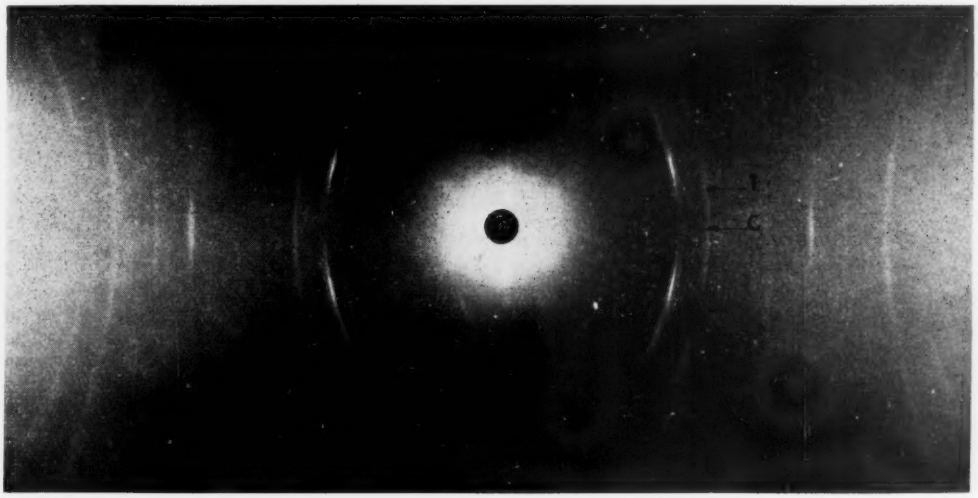


Fig. 6—X-ray photograph of hard-drawn wire, 0·036 in. dia. Region near centre of wire. α phase lines shown. (*T* and *C* as in Fig. 5)

The orientation of the ferrite phase is more complex than might appear to be the case at first sight and cannot be fully established by reference to the table of Bozorth.[9, 10] This is apparent when photographs such as Fig. 8 are studied carefully.

The orientation, even at the centre of the wire, is not perfectly developed, and there is sufficient scatter about the ideal peak positions on the diffraction rings to obscure minor differences which might be critical. This provides a reason why it is desirable to use molybdenum radiation and sufficient depth of film to give as complete a diffraction pattern as possible. The work of Neerfeld and Mathieu[7] mentioned in the Introduction was based on ordinary strip Debye-Scherrer photographs which would not give such complete information. The ordinary method of interpretation was sufficient to show that the orientation in the present case could not in fact be a ⟨210⟩ texture as proposed by Neerfeld and Mathieu,[7] although it resulted from somewhat different conditions of deformation. Nor was the texture the simple ⟨110⟩ typical of body-centred cubic metals.

The best explanation of the texture would probably be achieved by considering the relationship between the ferrite and austenite crystal lattices.

Crystallographic Relationships between Austenite and Ferrite

If the orientation of the austenite is already established as in the annealed wire, then that of the ferrite is assumed to arise by transformation according to some mechanism which results in a mutual relationship between the two crystal lattices. This relationship determines which directions in the ferrite phase lie parallel to the wire axis. The problem is to decide which of the relationships, as proposed for the transformation by different investigators, gives the ferrite texture which would account for the diffraction pattern as observed.

The various transformation mechanisms postulated by different investigators are based upon or lead to the orientation relationships indicated in Table IV, where the ' transformation axes ' are described by a set of three mutually perpendicular directions in the α phase which lie respectively parallel to certain directions in the γ phase. The indices of typical sets of transformation axes are given in the table, although other sets could equally well have been chosen.

The first relationship in Table IV is the familiar one of Kurdjumov and Sachs,[14] and is most commonly observed for martensite or α-iron formed in iron–carbon alloys on quenching. The second relationship has been obtained for an Fe–30% Ni alloy after compression[15] and also in wire of the same kind of alloy.[16] The third relationship was claimed by the authors for the formation of α in an 18/8 Cr–Ni stainless steel wire deformed in tension.[7, 8] This is the relationship mentioned in the Introduction. The fourth relationship is intermediate between the first and second and was derived for a quenched Fe–Ni–C alloy. After tempering, the relationship changed and the mutual orientation was very near to the second (Nishiyama). Also noted is the relationship due to Bain.[18] This is generally considered to be improbable and there is no definite experimental evidence for it. It has, however, been examined for the sake of completeness although it is not considered necessary to report the results in the same detail as for the other cases.

The basis of consideration in determining possible orientations of the α phase is:

(i) The predominant orientation of the γ phase is ⟨111⟩. It is only necessary to consider this orientation, as the ⟨100⟩ and twin components are small

(ii) The mutual lattice relationships in Table IV enable the calculation in any given case, of a direction in the α phase which lies parallel to a γ ⟨111⟩ direction. Call the direction $[UVW]$.

(iii) $[UVW]$ will generally be given by non-integral indices, and more than one direction may be possible because the transformation axes can be chosen in a number of different ways.

This last point may be illustrated by reference to a particular case which is represented by Fig. 9, based on a diagram due to Nishiyama[15] and later used by Nishiyama and Doi.[19] If the applied stress is a simple tension or compression perpendicular to the (111) plane, then the ⟨112⟩ shear directions are as shown in this figure. In this ' ideal ' case there is no shear

Table III

INDICES AND ANGLES FOR TWINS ON ($\bar{1}11$) PLANE WITH WIRE AXIS [111]

Form of Plane $\{hkl\}$ and Multiplicity (p)	Individual Plane $(h_1k_1l_1)$	Plane in "N" (Fig. 2b) Parallel to $(h_1k_1l_1)$ in "T", i.e. $(h_2k_2l_2)$	Angle between Normal to $(h_1k_1l_1)$ i.e. $[h_2k_2l_2]$ and Wire Axis = [111]
{100}	(100)	(122)	15° 48′
(3 × 2)	(010)	(21$\bar{2}$)	78° 54′
	(001)	(2$\bar{2}$1)	78° 54′
{110}	(110)	(110)	35° 16°
(6 × 2)	(101)	(101)	35° 16′
	(011)	(4$\bar{1}\bar{1}$)	74° 12°
	(1$\bar{1}$0)	($\bar{1}$14)	57° 1′
	(10$\bar{1}$)	($\bar{1}$41)	57° 1′
	(01$\bar{1}$)	(01$\bar{1}$)	90°
{111}	(111)	(511)	38° 57′
(4 × 2)	(1$\bar{1}$1)	($\bar{1}$11)	70° 32′
	(1$\bar{1}$1)	(1$\bar{1}$5)	56° 15′
	(11$\bar{1}$)	(151)	56° 15′
{311}	(311)	(755)	9° 27′
(12 × 2)	(131)	(31$\bar{1}$)	58° 31′
	(113)	(3$\bar{1}$1)	58° 31′
	(3$\bar{1}\bar{1}$)	($\bar{1}$77)	41° 2′
	(13$\bar{1}$)	($\bar{7}$17)	86° 40′
	(1$\bar{1}$3)	($\bar{7}$71)	86° 40′
	(3$\bar{1}$1)	(113)	29° 30′
	(13$\bar{1}$)	($\bar{1}$13)	79° 59′
	(1$\bar{1}$3)	(5$\bar{5}$7)	66° 2′
	(31$\bar{1}$)	(131)	29° 30′
	(13$\bar{1}$)	(57$\bar{5}$)	66° 2′
	(11$\bar{3}$)	($\bar{1}$31)	79° 59′

Note.—The full multiplicity p includes planes represented by a change of sign of all indices, so that angles for only half the planes need be recorded. The other angles are 180° minus those given.

Table IV

LATTICE RELATIONSHIPS FOR THE TRANSFORMATION $\gamma \rightarrow \alpha$ IRON

Typical sets of crystallographic directions which are respectively parallel in each phase and mutually perpendicular ('transformation axes')

I Kurdjumov and Sachs[14]		II Nishiyama and Wassermann[15, 16]		III Neerfeld and Mathieu[7, 8]		IV Greninger and Troiano[17]	V Bain[18]	
γ phase	α phase	γ phase	α phase	γ phase	α phase		γ phase	α phase
$[11\bar{1}]$	[110]	$[11\bar{1}]$	[110]	$[11\bar{1}]$	[210]	Not represented by	[100]	$[1\bar{1}0]$
[011]	$[1\bar{1}1]$	[011]	[001]	[011]	[001]	integral indices, but	[010]	[110]
$[2\bar{1}1]$	$[\bar{1}12]$	$[2\bar{1}1]$	$[1\bar{1}0]$	$[2\bar{1}1]$	$[1\bar{2}0]$	lies between I and II	[001]	[001]

stress component in the directions lying in the (111) plane, whilst the shear stress component is twice as great in three of the remaining directions (thicker arrows in Fig. 9) as it is in the other six. If the stress conditions are 'ideal,' transformation will proceed by shear along the three most favourable directions, but if they are not 'ideal,' the transformation would probably involve all these nine shear directions, if not to a lesser degree the three contained in the (111) plane itself. Such a condition would apply in the case of wire drawing. The same kind of considerations would follow, whatever the actual mechanism of transformation. For the present purpose, however, it is only necessary to consider the possible ways in which the mutual relationship between the latices can be fulfilled without necessarily entering into assumptions about the actual mechanism involved.

For the first three cases in Table IV any set of transformation axes including the $\langle 111 \rangle$ direction parallel to the wire axis would lead at once to either a $\langle 110 \rangle$ (cases I and II) or a $\langle 210 \rangle$ orientation for the α-phase. Since these orientations were not observed they could only have been present if at all as minor components. For the other possible sets of transformation axes in which the $\langle 111 \rangle$ direction is not the one lying along the wire axis the situation is more complicated. For these cases (and for any general case) the method of calculation is outlined in Appendix I. This method of calculation gives the indices $[UVW]$ of directions in the ferrite phase parallel to [111] in the austenite phase. In the case of the relationship proposed by Greninger and Troiano (*see* Table IV), a graphical method had to be used. The values of $[UVW]$ obtained for the five possible sets of axial relationships are listed in Table V, which excludes cases where the $\langle 111 \rangle$ type transformation axis is parallel to the wire axis.

Application to Orientation of Ferrite Phase

The final stage in the process of interpreting the diffraction pattern for the ferrite phase consisted in using the values of $[UVW]$ in Table V to calculate a diffraction pattern to be compared with the observed pattern. The distribution of diffracted intensity round

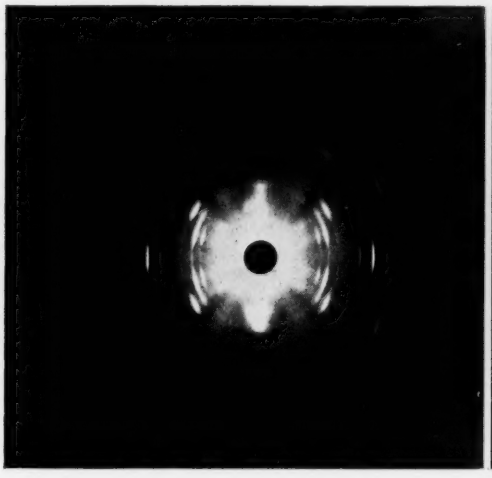


Fig. 7—Bright annealed wire, steel *A*, 0·0136 in. dia., etched to 0·0045 in. Mo$K_{\alpha\beta}$ radiation. Cylindrical camera

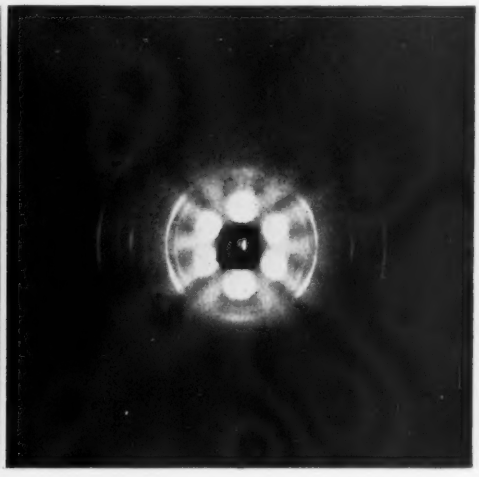


Fig. 8—Hard-drawn wire, steel *B*, 0·055 in. dia, etched to 0·012 in. Lines of ferrite phase. Mo$K_{\alpha\beta}$ radiation. Flat film camera

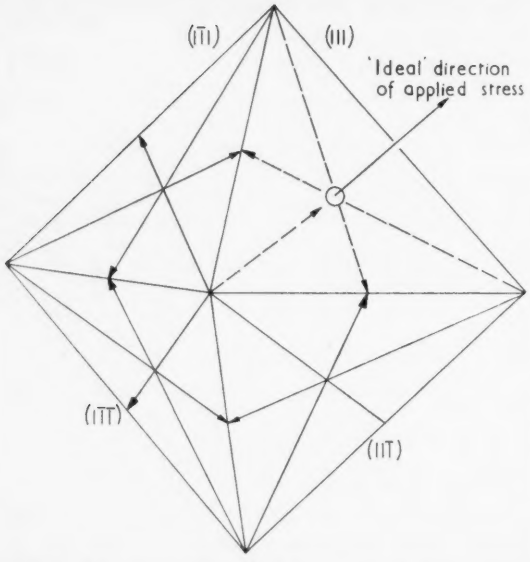


Fig. 9—Slip planes {111} and directions of shear <112> for face-centred cube γ phase (after Nishiyama and Doi[19])

the first five diffraction rings in Fig. 8 was obtained from microphotometer records kindly provided for the author by Dr. R. J. Wakelin of G.K.N. Group Research Laboratory. The microphotometer used was equipped with a special rotating film holder for this purpose. The microphotometer intensity traces were replotted in terms of the angle ρ on a horizontal scale, for one quadrant representing the mean for the four quadrants.

The calculation of the theoretically possible diffraction patterns was carried out for the first few diffraction rings ((110), (200), and (211), with limited comparison for (310)). The non-integral values of U, V, and W gave a considerable number of values of ρ. The scatter of orientation about these ideal values was allowed for by taking a Gaussian distribution of intensity with $3\sigma = 15°$ (thus 68% of the intensity lay in the range $\rho \pm 5°$ and 95% in the range $\rho \pm 10°$). Distributions with $3\sigma = 10°$ appeared to be too sharp. A calculated diffraction pattern was established for each of the directions $[UVW]$ as recorded in Table V. No clear similarities with the observed pattern were apparent when these calculated patterns were considered separately. They were then added together for each axial relationship in the relative proportions indicated.

The comparison of calculated and observed intensity distributions for the first three diffraction rings is then represented by Fig. 10. The pattern for the axial relationship due to Bain was considered but is not included here. Figure 10 suggests on close examination that the best agreement is obtained with case II (Nishiyama and Wasserman's relationship). However the agreement is not perfect. The observed peak round 60° for the line (110) is not as broad as that calculated. This could be due to the fact that although all the possible sets of transformation axes as suggested, e.g., by Fig. 9, have been operative, they should not have been given absolutely equal weight. Consideration of all three rings supplemented by some confirmation from the (310) ring support the view that case II gives the best comparison, and the others are excluded. Figure 10 also confirms that a <210> orientation does not explain the experimental results. On the other hand, a <320> orientation would give a pattern which resembles the observed pattern more closely, but not perfectly.

Figure 11*a* shows where the two possible directions for the Nishiyama relationship would lie in relation to other crystallographic directions. In Fig. 11*b*, these directions are plotted in a stereogram. To a first approximation the diffraction pattern might be

Table V

DIRECTIONS [UVW] IN α PHASE PARALLEL TO [111] IN γ PHASE FOR DIFFERENT AXIAL RELATIONSHIPS

Axial Relationship	[U, V, W]	Relative Frequency of Occurrence	Nearest Direction with Simple Indices	Angular Separation
I. Kurdjumov and Sachs[14]	[4·16, 1, 5·16]	1	[415]	45′
	[11·90, 1, 19·80]	1	[305]	2° 30′
	[10·40, 4·95, 1]	1	[210]	5° 7′
II. Nishiyama and Wasserman[15, 16] ...	[2·094, 1, 0]	1	[210]	1° 6′
	[5·83, 1, 8·36]	2	[618]	2°
			[304]	5° 57′
III. Neerfeld and Mathieu[7, 8]	[1·037, 1, 0]	1	[110]	1° 1′
	[1, 8·036, 0]	1	[180]	< 10′
	[1·867, 1, 2·996]	2	[213]	1° 43′
	[1, 6·335, 9·350]	2	[023]	5° 10′
IV. Greninger and Troiano[17]	[2·24, 1·04, 1]	1	[211]	...*
	[1·56, 1, 4·52]	1	[329]	...*
	[1, 2·54, 1·60]	1	[253]	...*
V. Bain[18]	[1·414, 1, 0]	1	[750]	30′

*Angles not given in this case as the graphical method does not give *U*, *V*, and *W* to sufficient accuracy

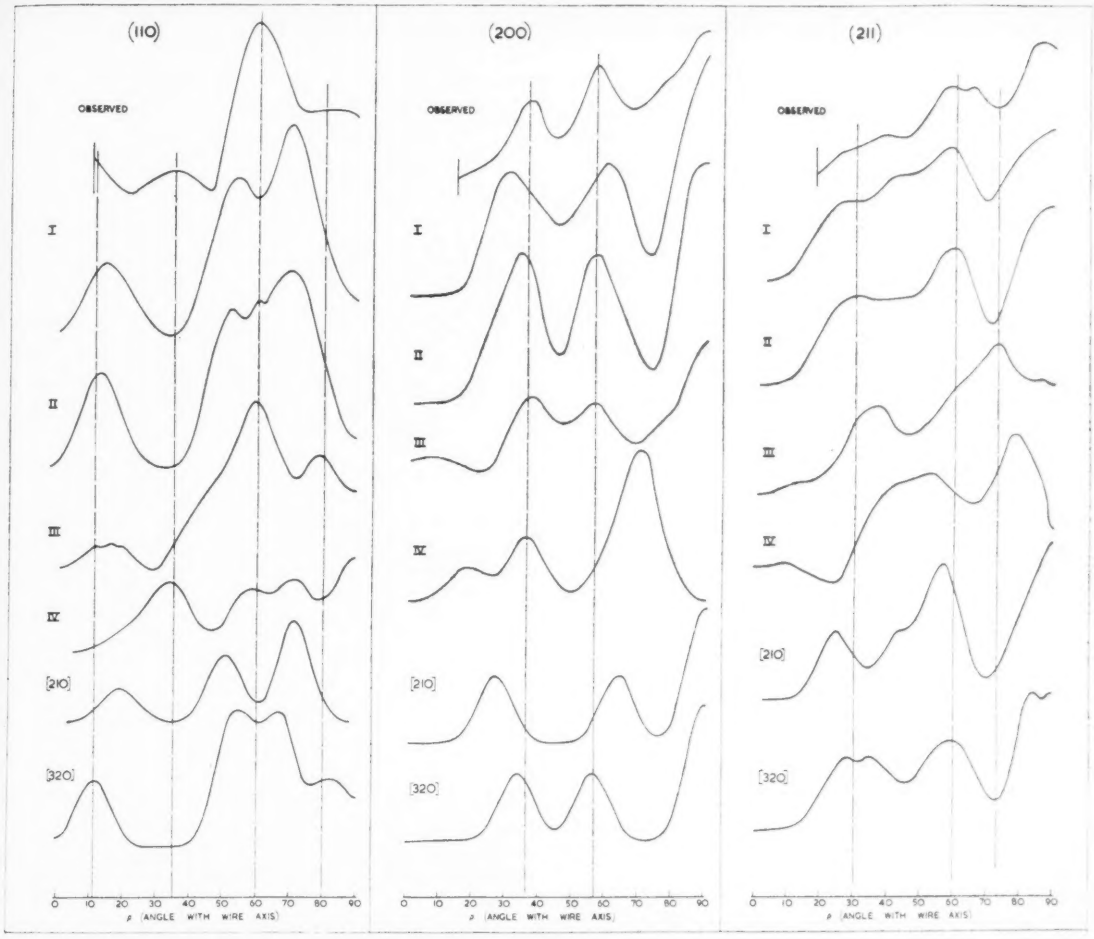


Fig. 10—Comparison of observed intensity distribution (uncorrected for absorption) with distribution calculated for four axial relationships and two simple textures

regarded as arising from a mean orientation near to the point C which is only 4° from [320]. It will also be noted that if the transformation only employed sets of axes corresponding to the point A the orientation would be nearly identical with ⟨210⟩, a fact pointed out by Nishiyama and Doi.[11] It was clear that no single choice of axes in this case (or for any of the other cases) would account for the observed diffraction pattern. This does not rule out the possibility that in simple compression or tension, as in the case of Neerfeld and Mathieu, a more restricted choice of transformation axes is possible.

CONCLUSIONS

(1) Austenitic stainless-steel wire (18/8, Cr–Ni) develops a preferred orientation during the wire-drawing process. Under the normal industrial annealing process this orientation is not removed.

(2) The orientation is considerably sharper towards the centre of the wire than at the surface.

(3) The predominant component in the observed texture is represented by a cube diagonal, i.e. a ⟨111⟩ direction, lying parallel to the wire axis. There is a small fraction of grains with a cube edge ⟨100⟩ direction parallel to the wire axis. This fraction may vary, but generally does not appear to exceed 10% of the material, and tends to decrease towards the centre of the wire.

(4) Certain minor diffraction effects can be ascribed to the existence of twins which are typical of annealed face-centred cubic crystals, and were observed microscopically in the annealed wire. The twins appear to persist in subsequently deformed wire, although the grains may be severely distorted and broken up by the deformation.

(5) Cold deformation during wire drawing causes transformation of austenite to ferrite. The maximum amount of ferrite that can form depends on the composition, and the actual amount in a given wire may be very small or zero at the surface of the wire, but increases towards the centre of the wire. This effect had been previously reported, and its possible dependence on nitrogen content is referred to in Appendix II.

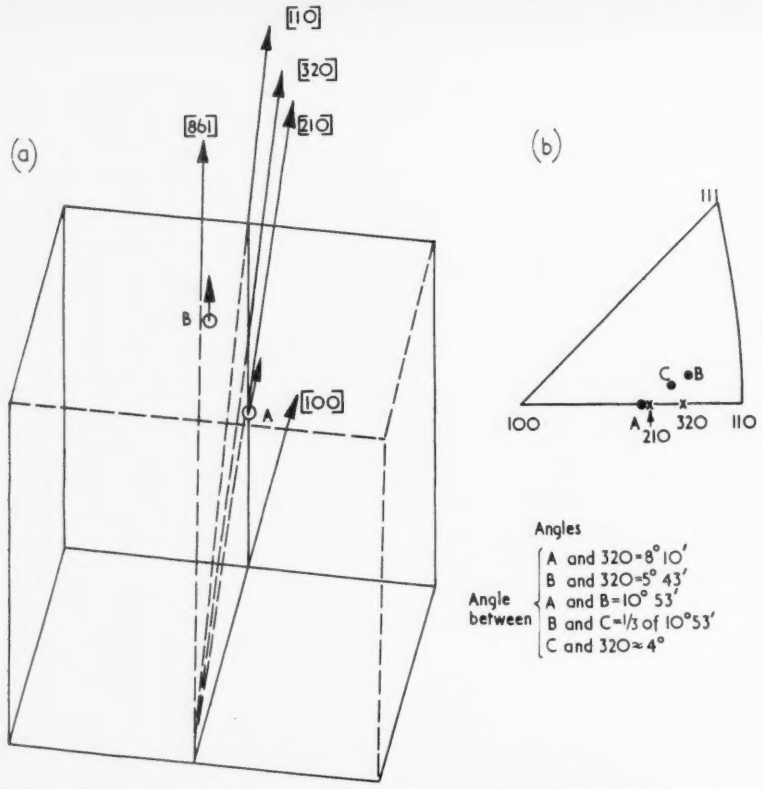


Fig. 11—Body-centred cubic α phase. Possible positions of wire axis (with γ [111] orientation and axial relationship according to Nishiyama and Wasserman[15, 16])

(6) The ferrite phase itself possesses a preferred orientation, which does not, however, correspond to the texture usually observed for a body-centred cubic metal.

(7) An interpretation of the observed texture has been attempted on the assumption that it is dependent upon a mutual crystallographic relationship to the already oriented austenite phase from which it has formed. Given the orientation of the austenite phase (as predominantly ⟨111⟩), and axial relationships proposed by different investigators for the transformation $\gamma \rightarrow \alpha$ iron, certain directions in the ferrite phase may lie along the wire axis. Calculated diffraction patterns agree closest with the observed when the axial relationship of Nishiyama and Wasserman is chosen.

(8) The agreement is not perfect, but is considered to be sufficiently close to justify the conclusion and to exclude the other possibilities considered. For a given axial relationship, more than one set of transformation axes may be chosen giving more than one direction in the ferrite phase which can lie parallel to the wire axis. The conditions of deformation under wire drawing are complex and would justify the actual choice made here of more than one set of transformation axes. Under simple tension a more restricted choice of transformation axes could lead to an orientation very near to the ⟨210⟩ which Neerfeld and Mathieu[7] claimed to have found. This orientation need not necessarily have demanded the existence of the new axial relationship which they postulated.[19, 20]

Acknowledgments

The author is grateful to Mr. F. H. Saniter, Director of Research, The United Steel Companies Ltd., for permission to publish this paper. Thanks are due to Dr. R. J. Wakelin of the G.K.N. Group Research Laboratory for his kindness in providing the circular microphotometer records, and to Dr. H. Hughes for assistance in the experimental work. The author also thanks the referee for drawing his attention to the point about nitrogen content.

APPENDIX I

Derivation of Orientation of Ferrite Phase Given the Orientation of the Austenite Phase

The problem is reduced to finding a direction $[UVW]$ in the ferrite phase which lies parallel to [111] in the γ phase, i.e. to the wire axis, given that the mutual relationship between the two lattices is governed by one or other of the set of conditions indicated in Table IV. Case IV (Greninger and Troiano) cannot be calculated as readily and in this case a graphical method was used. There is no need to consider the minor ⟨100⟩ component in the austenite orientation as the bulk of the material has the ⟨111⟩ orientation.

The following notes are intended to outline the mathematical calculation. The method is based upon the treatment used by Jaswon and Wheeler[21] in a

study of atomic displacements in the transformation of austenite to martensite. Conditions such as those given in Table IV may be represented in general by three directions at right-angles whose indices are:

In γ phase		In α phase
$[u_1v_1w_1]$	parallel to	$[U_1V_1W_1]$
$[u_2v_2w_2]$	,, ,,	$[U_2V_2W_2]$
$[u_3v_3w_3]$	,, ,,	$[U_3V_3W_3]$

These directions are the ' transformation axes '.

Supposing the face-centred cubic unit cell (F) is replaced by a unit cell (T) with the transformation axes as its cell edges. Then the indices of any direction $[uvw]$ in the γ phase may be transformed to new indices referred to these new axes by a matrix we denote by (T/F)

$$\text{or } [u'v'w'] = (T/F)\,[uvw]$$

In the body-centred cubic lattice referred to its transformation axes the same indices $[u'v'w']$ apply and it remains to transform these to indices $[UVW]$ referred to the normal cube axes for this phase. This transformation may be represented by:

$$\begin{aligned} [UVW] &= (B/T)\,[u'v'w'] \\ \text{i.e. } [UVW] &= (B/T)\,(T/F)\,[uvw] \\ &= A.\,[uvw] \end{aligned}$$

where A is a matrix which is the matrix product[22] of (B/T) and (T/F). The terms in these separate matrices are of the form in (T/F)

$$\frac{u_1}{\sqrt{(u_1^2 + v_1^2 + w_1^2)}} = \frac{u_1}{\sqrt{N_1}} \text{ etc.}$$

and in (B/T)

$$\frac{U_1}{\sqrt{(U_1^2 + U_2^2 + U_3^2)}} = \frac{U_1}{\sqrt{N_1'}}$$

but because these matrices operate in the opposite sense rows in one are analogous to columns in the other. It is not necessary to write these matrices in full, but the product is recorded here:

$$A = \begin{bmatrix} \left(\frac{U_1u_1}{\sqrt{N_1N_1'}} + \frac{U_2u_2}{\sqrt{N_2N_2'}} + \frac{U_3u_3}{\sqrt{N_3N_3'}}\right)\left(\frac{U_1v_1}{\sqrt{N_1N_1'}} + \frac{U_2v_2}{\sqrt{N_2N_2'}} + \frac{U_3v_3}{\sqrt{N_3N_3'}}\right)\left(\frac{U_1w_1}{\sqrt{N_1N_1'}} + \frac{U_2w_2}{\sqrt{N_2N_2'}} + \frac{U_3w_3}{\sqrt{N_3N_3'}}\right) \\ \left(\frac{V_1u_1}{\sqrt{N_1N_1'}} + \frac{V_2u_2}{\sqrt{N_2N_2'}} + \frac{V_3u_3}{\sqrt{N_3N_3'}}\right)\left(\frac{V_1v_1}{\sqrt{N_1N_1'}} + \frac{V_2v_2}{\sqrt{N_2N_2'}} + \frac{V_3v_3}{\sqrt{N_3N_3'}}\right)\left(\frac{V_1w_1}{\sqrt{N_1N_1'}} + \frac{V_2w_2}{\sqrt{N_2N_2'}} + \frac{V_3w_3}{\sqrt{N_3N_3'}}\right) \\ \left(\frac{W_1u_1}{\sqrt{N_1N_1'}} + \frac{W_2u_2}{\sqrt{N_2N_2'}} + \frac{W_3u_3}{\sqrt{N_3N_3'}}\right)\left(\frac{W_1v_1}{\sqrt{N_1N_1'}} + \frac{W_2v_2}{\sqrt{N_2N_2'}} + \frac{W_3v_3}{\sqrt{N_3N_3'}}\right)\left(\frac{W_1w_1}{\sqrt{N_1N_1'}} + \frac{W_2w_2}{\sqrt{N_2N_2'}} + \frac{W_3w_3}{\sqrt{N_3N_3'}}\right) \end{bmatrix}$$

This expression is of quite general application for the transformation

$$[UVW] = A\,[uvw]$$

where $[uvw]$ is a direction in the austenite phase and $[UVW]$ a parallel direction (not necessarily represented by integral indices) in the ferrite phase.

When $[uvw] = [111]$

U = sum of top row of terms in A
V = ,, ,, middle ,, ,, ,, ,, ,,
W = ,, ,, bottom ,, ,, ,, ,, ,,

Thus

$$U = \left(\frac{u_1 + v_1 + w_1}{\sqrt{N_1}}\right)\frac{U_1}{\sqrt{N_1'}} + \left(\frac{u_2 + v_2 + w_2}{\sqrt{N_2}}\right)\frac{U_2}{\sqrt{N_2'}} + \left(\frac{u_3 + v_3 + w_3}{\sqrt{N_3}}\right)\frac{U_3}{\sqrt{N_3'}}$$

with strictly parallel expressions for V and W. These expressions were applied in turn to the various sets of transformation axes given in Table IV covering the possible different ways in which the mutually perpendicular sets of directions can be chosen. The amount of actual calculation is greatly simplified by the fact that the sets of axes are the same for the first three cases in Table IV, whilst the choice of axes is such that many of the variations would only result in changes of sign or permutations of U, V, and W. When all possibilities are considered, excluding the simple cases with the <111> type transformation axis parallel to the wire axis, the results of Table V are obtained.

APPENDIX II

Note on the Effect of Nitrogen Content

One of the referees made the interesting suggestion that the wires could have been contaminated at their surfaces by nitrogen or carbon and that this might explain why the wires showed less α at the outside than near the centre, and account for differences in the total amounts of α between thicker and thinner wires. Nitrogen pick-up could occur during the bright-annealing treatment and the carbon could come from the lubricating compound. The latter possibility is unlikely and could only have affected the results, if at all, after the second bright-annealing treatment at 0·0135 in. dia., since the original wire was lead-coated and this was removed before the first bright-annealing treatment at 0·036 in. dia. The possibility of nitrogen absorption has, however, been considered further and some chemical analyses for nitrogen have been obtained.

The total nitrogen contents of some of the wires are:

Steel A	(i)	At 0·08 in. dia.	0·0715%
	(ii)	At 0·032 in. dia. (light drawn)	0·078%
	(iii)	At 0·0136 in. dia. (hard-drawn)	0·0735%
	(iv)	At 0·004 in. dia. (hard-drawn)	0·077%
Steel B			0·064%

These figures are somewhat high for stainless steel of this type, but not exceptional. The differences for steel A can be accounted for. There is a small nitrogen

pick-up in bright-annealing after drawing from 0·08 (i) to 0·036 which is not affected by the immediately following light draw to 0·032 (ii). Hard drawing could be accompanied by removal of some nitrogen probably by surface abrasion and so there is a decrease. The bright-annealing after (iii) could give a rise in nitrogen content; although presumably some of this is lost again on drawing, the net result is an overall increase. These differences in total nitrogen content cannot be regarded as likely to have any significant effect on the total amounts of ferrite.

The distribution of nitrogen across a wire was tested for the 0·004 in. dia. hard-drawn wire by solution of successive layers in acid and analysis of the solutions for nitrogen. The results obtained were:

Weight Dissolved, % of total	Initial and Final Dia., in.	Nitrogen, wt- %
4·54	0·0040 to 0·0039	0·204
7·74	0·0039 to 0·00375	0·106
43·06	0·00375 to 0·0027	0·068
44·66	0·0027 to centre	0·068
(Remainder)		

It is clear from these results that there is a markedly higher nitrogen content at the surface but that the average content is very nearly reached at only 0·0005 in. below. The exact effect of nitrogen on the amount of ferrite under these conditions is not known but on the basis of the kind of principles discussed by the author elsewhere[23] it seems likely that a difference of 5% in the amount of ferrite could be caused by differences of the order of 0·05%, say, in the amount of nitrogen. Since the X-ray diffraction pattern in this case derives from a substantial proportion of material in the affected range, it is reasonable to conclude that the amount of ferrite detected at the surface will be less due to the presence of nitrogen. It is important to realize that the tendency for ferrite to increase towards the centre of the wire continues well below the surface layers, and nitrogen is not in general the determining factor, although it may have a pronounced effect just at the surface. Otherwise the explanation previously given[4] appears to be more generally correct.

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Thermal Conductivity and Electrical Resistivity of a 0·4–0·5% Manganese Steel

By R. W. Powell, D.Sc., Ph.D., F.Inst.P., and R. P. Tye

SYNOPSIS

Arising from the publication by Hogan and Sawyer of values for the thermal and electrical conductivities of a steel containing 0·48% of manganese as the main alloying constituent, it was considered desirable to undertake independent measurements on a sample of steel En 32A of similar composition.

Values are presented covering the temperature range 50–700° C. which differ considerably from those of Hogan and Sawyer, but do conform to the general pattern for the variation of the conductivities of irons and steels with temperature. 1209

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A RECENT PAPER by Hogan and Sawyer[1] gave some results for the thermal and electrical conductivities of a 1010 steel containing 0·48% of manganese as the main alloying constituent. These do not conform to the values to be expected for a steel of this or any other type.

At normal temperatures the thermal conductivity

Table I
COMPOSITIONS OF THE STEELS, wt-%

Type of Steel	C	Mn	Si	Ni	Cr	P	S	Fe
1010	0·08	0·48	0·18	...	...	0·014	0·03	Bal.
*BGK*1	0·1	0·42	0·21	0·23	0·07	0·018	0·036	Bal.
Raisch's sample	0·12	0·5	0·12	...		Total 0·5		Bal.

corresponded to that of Armco iron,[2] whereas a much lower value would be expected, as Raisch[3] found for a similar steel. On the other hand, the value obtained by Hogan and Sawyer at 800° C was some 50% greater than that of iron at that temperature, while the present authors' experience has been that the thermal conductivities of irons and steels converge at such high temperatures and cover a range of values differing only by about 20%.[4, 5]

A similar convergence has been noticed for the electrical resistivity[6]; at 800° C the resistivities of a fairly representative range of steels,[7] including carbon steels, low-alloy steels, and high-alloy steels, all came between 107·3 and 120·4 $\mu\Omega$ cm²/cm whereas Hogan and Sawyer's value is 142·8 $\mu\Omega$ cm²/cm at 800° C.

Because of their high thermal conductivity values and high electrical resistivity values at the higher temperatures, Hogan and Sawyer's results indicate that the Lorenz function of steel 1010 increases from $4{\cdot}2 \times 10^{-8}$ at 100° C to $6{\cdot}3 \times 10^{-8}$ J Ω/s °C °K at 700° C, which is also contrary to the usual behaviour of steels and of most other metals.[4]

Results for six other metals were given in Hogan and Sawyer's paper and, as some of these results appeared reasonable, it was thought desirable to check the behaviour of a steel of similar composition to that tested by Hogan and Sawyer. A sample of steel referred to as *BGK*1 and conforming to the B.S. 970 En 32A specification was obtained from the British Iron and Steel Research Association and used for this purpose.

Table I gives the compositions of these two steels and of the steel tested by Raisch. The analysis for the 1010 steel was given by Dr. Hogan, and that for the *BGK*1 sample was supplied by B.I.S.R.A.

The sample of *BGK*1 steel was machined to a uniform diameter of 2·22 cm over a length of 11·5 cm and its thermal conductivity and electrical resistivity were determined to about 800° C, using the comparative longitudinal steady-state methods previously described.[4]

The results of these measurements were sent in graphical form to Hogan and Sawyer and this has led to some further measurements being made by

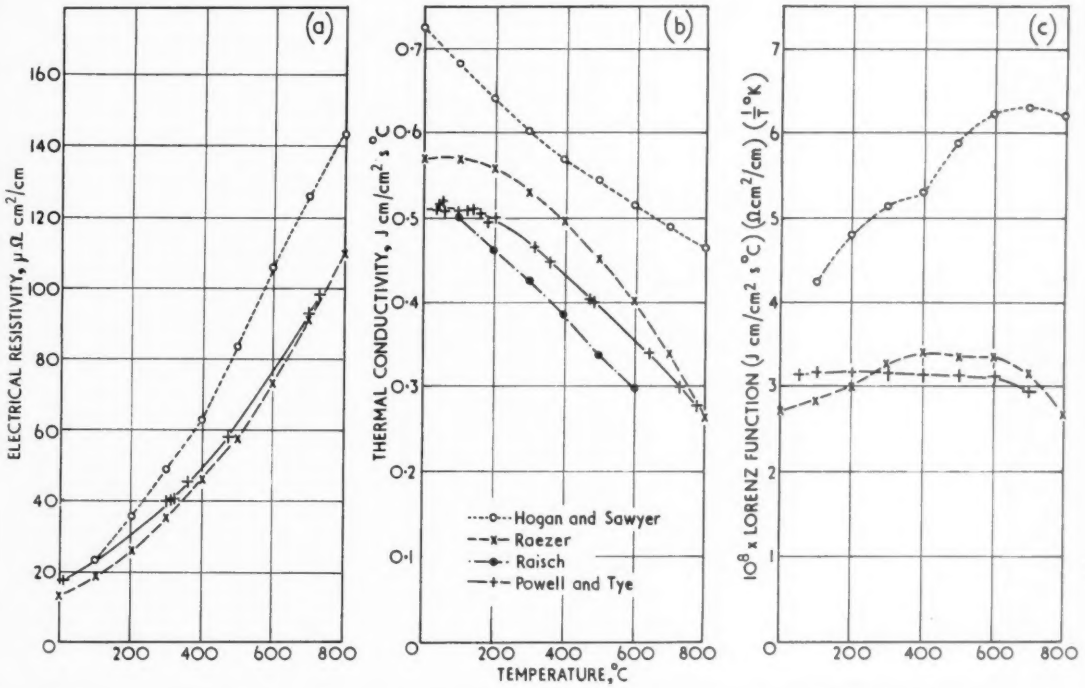

Fig. 1—(*a*) Electrical resistivity, (*b*) thermal conductivity, and (*c*) Lorenz function of 0·4–0·5% Mn steels

Table II

RESULTS FOR SAMPLE *BGK*1

Temperature, °C	Thermal Conductivity, J cm/cm² s °C	Electrical Resistivity, Ω cm²/cm	Lorenz Function, J Ω/s °C°K
50	0·51	$19·8\times10^{-6}$	$3·1\times10^{-8}$
100	0·51	23·2	3·2
200	0·50	30·0	3·2
300	0·47	38·7	3·2
400	$0·43_5$	48·5	3·1
500	0·40	61·0	3·1
600	$0·35_5$	76·2	3·1
700	0·31	92·3	2·9

Raezer[8] on a sample of basic C–1010 aluminium-killed steel of the following percentage composition: C 0·08, Mn 0·42, Si 0·10, P 0·015, S 0·03, Fe bal. The method used by Raezer for the thermal conductivity determination was a modification of that of Forbes, and was essentially the same as that of Hogan and Sawyer, but with some changes. Raezer estimated his uncertainty to be about $\pm 7·5\%$.

Figure 1 shows the results which have now been obtained for the electrical resistivity, thermal conductivity, and Lorenz function of the three similar steels. As regards the electrical resistivity, the value obtained for the *BGK*1 sample at room temperature is about 30% greater than Raezer's, but the values at high temperatures now show the anticipated convergence and it seems that Hogan and Sawyer's temperature coefficient of electrical resistivity must have been much too great; there is now little doubt that their thermal conductivity data were also much too high. The present authors' own observations are seen to agree closely with those of Raisch at 100° C, but these two curves diverge as the temperature increases. Raisch at the same time published thermal conductivity values for a Ni–Cr steel which, when compared with the results of Shelton and Swanger[9] for a comparable steel, show a similar tendency; hence there are grounds for believing Raisch's values to err on the low side at high temperatures. Raezer's curve, however, shows the anticipated convergence towards the authors' at high temperatures, although there is a difference of about 12% at lower temperatures. The curves for the Lorenz functions given by Raezer's and the authors' data agree rather more closely, suggesting that some of the foregoing differences are associated with real differences in the two samples. The unusually high Lorenz values indicated by Hogan and Sawyer have not been confirmed.

The method used in the present work is believed to give values of the thermal conductivity which are accurate to within $\pm 2\%$ over the full range covered. The values given in Table II relate to the particular sample of En 32A steel tested. The heat-treatment associated with the tests had no influence on values subsequently obtained at lower temperatures.

The present results conform well to the general pattern previously observed for the variation with temperature of the thermal conductivity and electrical resistivity of irons and steels.[5, 7, 10, 11]

Acknowledgment

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The Occurrence of Sigma-Phase in a High-Chromium–Nickel Steel

WITH PARTICULAR REFERENCE TO THE INFLUENCE OF SILICON

By L. Pryce, A.Met., F.I.M., H. Hughes, Ph.D., A.Inst.P., and K. W. Andrews, D.Phil., F.Inst.P.

SYNOPSIS

The mechanism and mode of formation of sigma-phase in a 25% Cr, 15% Ni steel have been studied and special attention has been paid to the influence of Si; this element promotes the formation of ferrite at solution temperatures and of sigma-phase at lower temperatures, increasing the speed of formation as well as the amount of sigma. A partly quantitative interpretation is given of the structures observed. The microscopical and X-ray investigation are supplemented by hardness and bend tests, which are fully consistent with the observed structural changes. The lowest ductility is reached only after long periods of heating when the sigma-phase has developed into large particles. 1181

A PREVIOUS COMMUNICATION from the authors' laboratories[1] described the mode of occurrence of sigma-phase in a 25% Cr, 15% Ni steel. Particular attention was paid to the effect of C content and the results were related to the equilibrium diagram of the system Fe–Cr–Ni; allowance was made for the influence of other alloying elements by means of suitable factors. The work has been extended to provide more definite information about the influence of Si, and the new results are reported here with some further conclusions deriving from both the earlier investigation and the present sequel. The results should be of wider interest in connection with heat-resisting steels of this type.

The following conclusions from the previous work are important here. With a base composition of 25% Cr, 15% Ni, about 0·6% Mn, and 1·7% Si, the mode of occurrence of σ-phase depends on the structure at the solution temperature. Steels with lower C content (0·06% and 0·09%) contain austenite and ferrite at solution temperatures between 1050° and 1250° C; sigma then forms at lower temperatures mainly from the ferrite phase. Higher C content (0·19–0·29%) gives a fully austenitic matrix, but may leave carbide out of solution at 1050° and 1150° C; at lower temperatures, this austenitic matrix precipitates carbide very readily, but some of this carbide is eventually replaced by σ-phase. It was shown that a formula previously proposed by Gow and Harder,[2] for indicating the dividing line between alloys which formed σ at 870° C and alloys which did not form σ, was not generally representative of such a division; it did in fact distinguish between the two modes of σ formation. Much longer periods of heating were involved in the present work and the periods used by Gow and Harder would probably not have been sufficient to produce σ from the fully austenitic alloys, although adequate for the others.

In the present study, phases have been identified by microscopical and X-ray methods, and their mode of occurrence and rapidity of formation have been observed. In addition, an assessment has been made of the mechanical effects of σ formation by means of hardness and bend tests.

EXPERIMENTAL WORK

Composition and Heat-treatment of Steels

The steels, made in an experimental 18-lb H.F. furnace and cast into 2½-in. sq. ingots, were forged to ½-in. dia. bars. The compositions of the four steels used in the earlier investigation were to be based on the composition 25% Cr, 15% Ni, 0·6% Mn, 1·7% Si, with increasing carbon content. The actual compositions were:

	No. 1	No. 2	No. 3	No. 4
C, %	0·06	0·09	0·19	0·29
Si, %	1·77	1·75	1·68	1·72
Mn, %	0·65	0·65	0·61	0·63
Cr, %	24·68	25·32	25·44	25·12
Ni, %	15·05	15·13	15·15	15·08

In the new series of steels it was intended that there should be two groups of four, one with lower C content (allowing for the formation of some ferrite at solution temperatures) and the other with higher C content (austenite only at solution temperatures). Within each group, Si was to be progressively increased to range from ½% to 2½%. The effect of Si could thus

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Table I

MICROSTRUCTURES

Solution-treated at 1050° C

Key
C = Carbide $M_{23}C_6$ σ = Sigma-phase
α = Ferrite γ = Austenite
$\bar{\sigma}$ = Trace of sigma

Steel No.	Solution-treated	Reheated at 700° C				Reheated at 900° C			
		4 h	100 h	1000 h	2000 h	4 h	100 h	200 h	1000 h
5	$\gamma + C$ network	$\gamma + C$ network	$\gamma + C$ network	$\gamma + C + \bar{\sigma}$	$\gamma + \bar{C} + \sigma$	$\gamma + C$	$\gamma + C$ (coalescing)	$\gamma + C + \sigma$	$\gamma + \bar{C} + \sigma$
6	$\gamma + C$ network	$\gamma + C$ network $+ \bar{C}$	$\gamma + C$ network $+ C$ (coalescing)	$\gamma + C + \bar{\sigma}$ at grain boundaries	$\gamma + C + \sigma$	$\gamma + C$ network $+ C$ Widmanstätten	$\gamma + C$ (coalescing) $+ \sigma$	$\gamma + C + \sigma$	$\gamma + \bar{C} + \sigma$
7	$\gamma + C + \bar{\alpha}$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C + \sigma$	$\gamma + \sigma + \bar{C}$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C + \sigma$	$\gamma + \bar{C} + \sigma$
8	$\gamma + C + \alpha$	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C$ (Widmanstätten) $+ (\alpha \rightarrow \sigma)$	$\gamma + C$ (Widmanstätten) $+ \sigma$	$\gamma + \sigma + \bar{C}$?	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C + \sigma$	$\gamma + \bar{C} + \sigma$
9	$\gamma + C + \bar{\alpha}$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + C + (\alpha \rightarrow \sigma)$	$\gamma + C + \sigma$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + C + (\overline{\alpha \rightarrow \sigma})$	$\gamma + \bar{C} + \sigma$	$\gamma + \bar{C} + \sigma$
10	$\gamma + C$ network and Widmanstätten	$\gamma + C$ (coalescing)	$\gamma + C$ (coalescing) $+ \bar{\sigma}$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \bar{\sigma}$	$\gamma + C$ coalesced at grain boundaries	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + C + \sigma$
11	$\gamma + C$	$\gamma + C$ (coalescing)	$\gamma + C$ (coalescing) $+ \bar{\sigma}$ at grain boundaries	$\gamma + C + \bar{\sigma}$	$\gamma + \sigma + \bar{C}$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + \bar{C} + \sigma$
12	$\gamma + C + \bar{\alpha}$ (α may be due to segregation)	$\gamma + C$ (coalescing)	$\gamma + C$ (coalescing) $+ \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + C + \sigma$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + C + \sigma$

Table II

MICROSTRUCTURES

Solution-treated at 1150° C

Key
C = Carbide $M_{23}C_6$ σ = Sigma-phase
α = Ferrite γ = Austenite
$\bar{\sigma}$ = Trace of sigma

Steel No.	Solution-treated	Reheated at 700° C				Reheated at 900° C			
		4 h	100 h	1000 h	2000 h	4 h	100 h	200 h	1000 h
5	$\gamma + \bar{C}$ network	$\gamma + C$ network	$\gamma + C$ precipitation at grain boundaries	$\gamma +$ general C precipitate $+ \bar{\sigma}$?	$\gamma + C + \bar{\sigma}$	$\gamma + \bar{C}$ network $+ \bar{C}$	$\gamma + C$ network $+ C$ (coalescing)	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$
6	$\gamma + \bar{C}$ network	$\gamma + C$ network	$\gamma + C$ precipitation. Heavy at grain boundaries	$\gamma +$ general C precipitate $+ \bar{\sigma}$ at grain boundaries	$\gamma + \sigma + C$	$\gamma + C$ network $+ C$	$\gamma + \bar{C} + \bar{\sigma}$ at grain boundaries	$\gamma + \bar{C} + \sigma$	$\gamma + \sigma + C$?
7	$\gamma + \alpha$	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ network	$\gamma + (\alpha \rightarrow \sigma) + \bar{C}$ network	$\gamma + (\alpha \rightarrow \sigma) + C$ striated	$\gamma + \bar{\sigma} + \bar{C}$	$\gamma + \bar{C}$ network $+ (\alpha \rightarrow \sigma)$	$\gamma + \bar{C} + (\alpha \rightarrow \sigma)$	$\gamma + \sigma + \bar{C}$	$\gamma + \sigma + \bar{C}$
8	$\gamma + \alpha$	$\gamma + (\alpha \rightarrow \sigma) + C$ network	$\gamma + (\alpha \rightarrow \sigma) + C$ network	$\gamma + \sigma + \bar{C}$	$\gamma + \sigma + \bar{C}$	$\gamma + C$ network $+ (\alpha \rightarrow \sigma)$	$\gamma + (\alpha \rightarrow \sigma) + C$	$\gamma + \sigma + C$	$\gamma + \sigma + \bar{C}$?
9	$\gamma + \bar{C}$ network + dispersed C	$\gamma + C$ network	$\gamma + C$ precipitation. Heavy at grain boundaries	As 100 h	$\gamma + \sigma + \bar{C}$	$\gamma + \bar{C}$ network + fine C precipitation $+ \overline{(\alpha \rightarrow \sigma)}$	$\gamma + C + \overline{(\alpha \rightarrow \sigma)}$	$\gamma + C + \sigma$	$\gamma + \sigma + \bar{C}$
10	$\gamma + C$ network	$\gamma + C$ network (coalescing)	As 4 h	$\gamma + C + \bar{\sigma}$	$\gamma + \bar{C} + \sigma$	$\gamma + \bar{C}$ network + general C precipitate	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + \sigma + \bar{C}$
11	$\gamma + C$	$\gamma + C + \bar{C}$ network	$\gamma + C$ (coalescing) + C network	$\gamma + C + \bar{\sigma}$	$\gamma + \sigma + \bar{C}$	$\gamma + \bar{C}$ network + C (coalescing)	$\gamma + C + \sigma$	$\gamma + \sigma + \bar{C}$	$\gamma + \sigma + \bar{C}$
12	$\gamma + C + \bar{C}$ network $+ \bar{\alpha}$ (segregation ?)	$\gamma + C + \bar{C}$ network	$\gamma + C + \bar{C}$ network $+ \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + \sigma + C$	$\gamma + C + \bar{\sigma}$	$\gamma + C + \sigma$	$\gamma + C + \sigma$	$\gamma + \sigma + C$

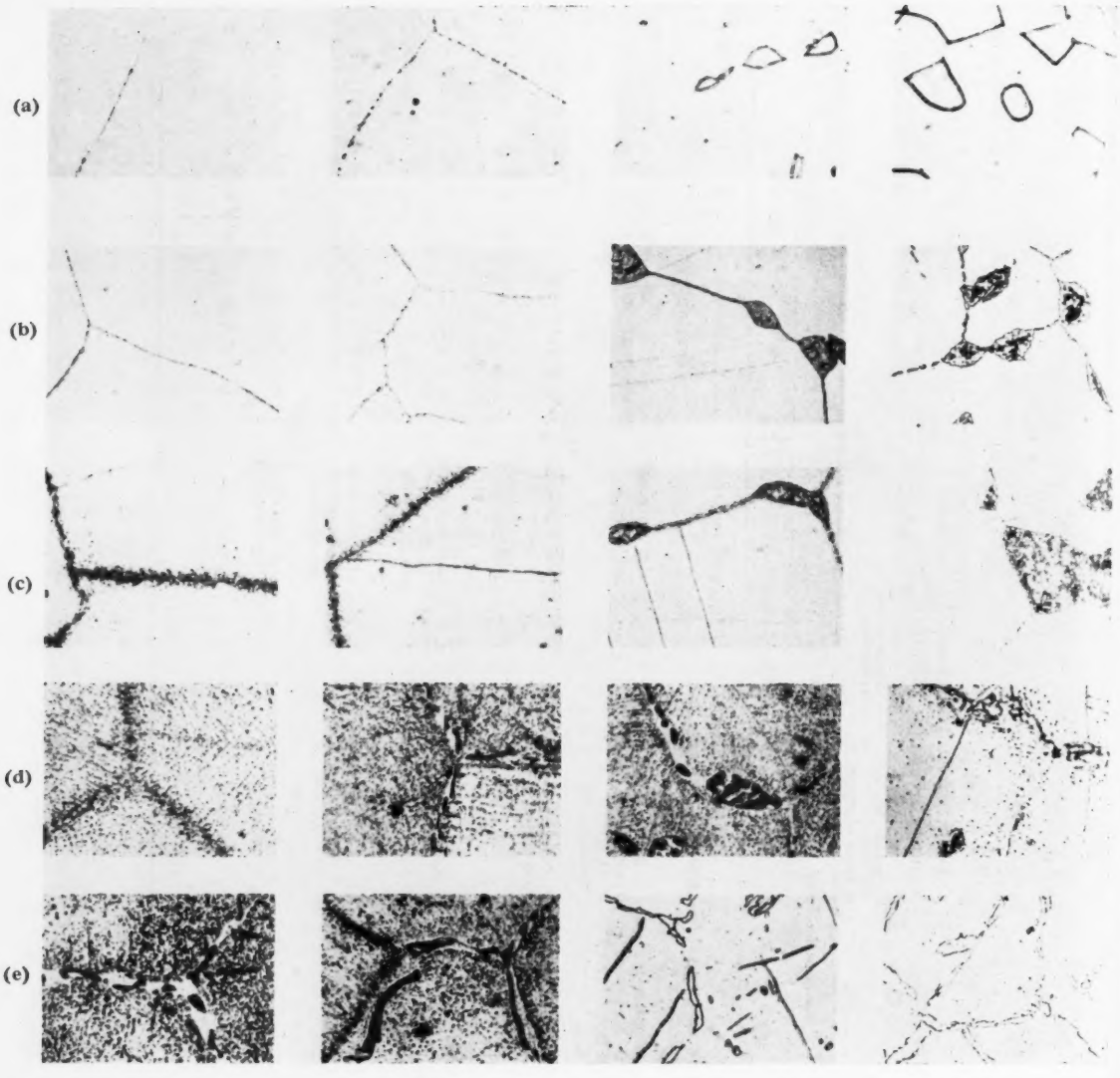

Fig. 1—Microstructures after heat-treatment × 750

be investigated at two C levels. The actual compositions were:

	No. 5	No. 6	No. 7	No. 8
C, %	0·12	0·13	0·13	0·12
Si, %	0·44	1·43	1·94	2·61
Mn, %	0·85	0·92	0·86	0·93
Cr, %	24·64	24·76	24·52	24·90
Ni, %	15·02	14·90	15·00	15·00

	No. 9	No. 10	No. 11	No. 12
C, %	0·22	0·22	0·24	0·22
Si, %	0·67	1·39	1·94	2·46
Mn, %	0·85	0·90	0·91	0·91
Cr, %	24·72	24·80	24·46	24·72
Ni, %	15·10	15·05	15·05	15·00

Specimens $\frac{1}{4}$ in. long were taken from each cast and prepared for microscopical examination after the following heat-treatments:

(i) Solution treatment at 1050°, 1150°, and 1250° C for 4 h, followed by water quenching

(ii) Treatment as in (i) with further heating at 700° C for periods of 4 h, 100 h, 1000 h, and 2000 h or at 900° C for 4 h, 100 h, 200 h, and 1000 h, followed by air-cooling. Some samples were reheated for 2000 h at 900° C and it was established that equilibrium was generally reached in 1000 h at this temperature.

In the previous work a ' solution temperature ' of

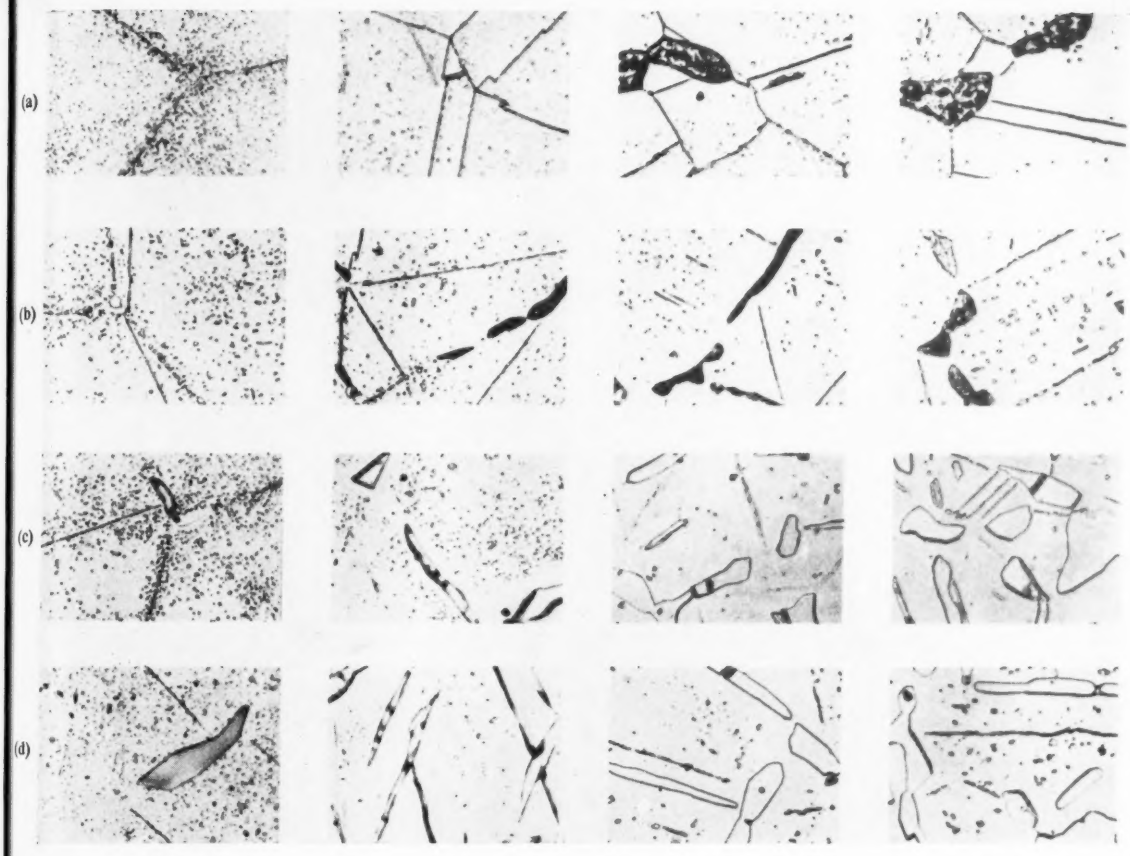

Fig. 1 (contd.)—Microstructures after heat-treatment × 750

950° C had been included, but it is doubtful whether any significance can be attached to the structures of the steels so heated, since a state of equilibrium had not been reached.

Determination of Structure and Properties

Microscopical examination was carried out after an electrolytic etch under standardized conditions in aqueous 10% oxalic acid solution, but confirmatory etches, described in the previous paper,[1] were also used on selected specimens. The results are given in Tables I–III and illustrated for the series in Table III (i.e. after solution at 1250° C) in Figs. 1 and 2.

Carbide and σ-phase were separated from the matrix by the usual electrolytic methods, and identified by X-ray powder photographs. The electrolyte was ferric-chloride solution, as it was found that σ was practically unattacked by this solution, whereas alcoholic hydrochloric acid tended to dissolve some of the σ. This part of the examination was confined to the solution-treated samples and the samples treated for 2000 h at 700° C and 1000 h at 900° C; the results are given in Table IV. In certain cases the weights of residue (as a percentage of the steel dissolved) were also obtained; these are plotted in Fig. 3.

The hardness measurements were made on the alloys in the solution-treated and final conditions (as for X-ray examination). Bend tests were carried out for the solution-treated conditions and for 100 h and 1000 h at each reheating temperature. For these tests the samples used had a $\frac{1}{2}$ in. × $\frac{1}{4}$ in. cross-section and were 3 in. long. They were bent round to an inner diameter of $\frac{1}{4}$ in. Results are illustrated in Figs. 4 and 5.

CONSIDERATION OF RESULTS

Reference to Tables I–III shows how the increasing of the solution temperature of the respective steels progressively reduced the amount of carbide both within the grains and at the grain boundaries, whilst in the low-C steels, the amount of ferrite in the microstructures has been considerably increased. No ferrite has been detected in the higher-C steels. These results are consistent with the influence of C as an austenite former, and with the fact that, when more carbide is dissolved, more Cr is available as a ferrite former. The influence of Si as a ferrite former is evident from

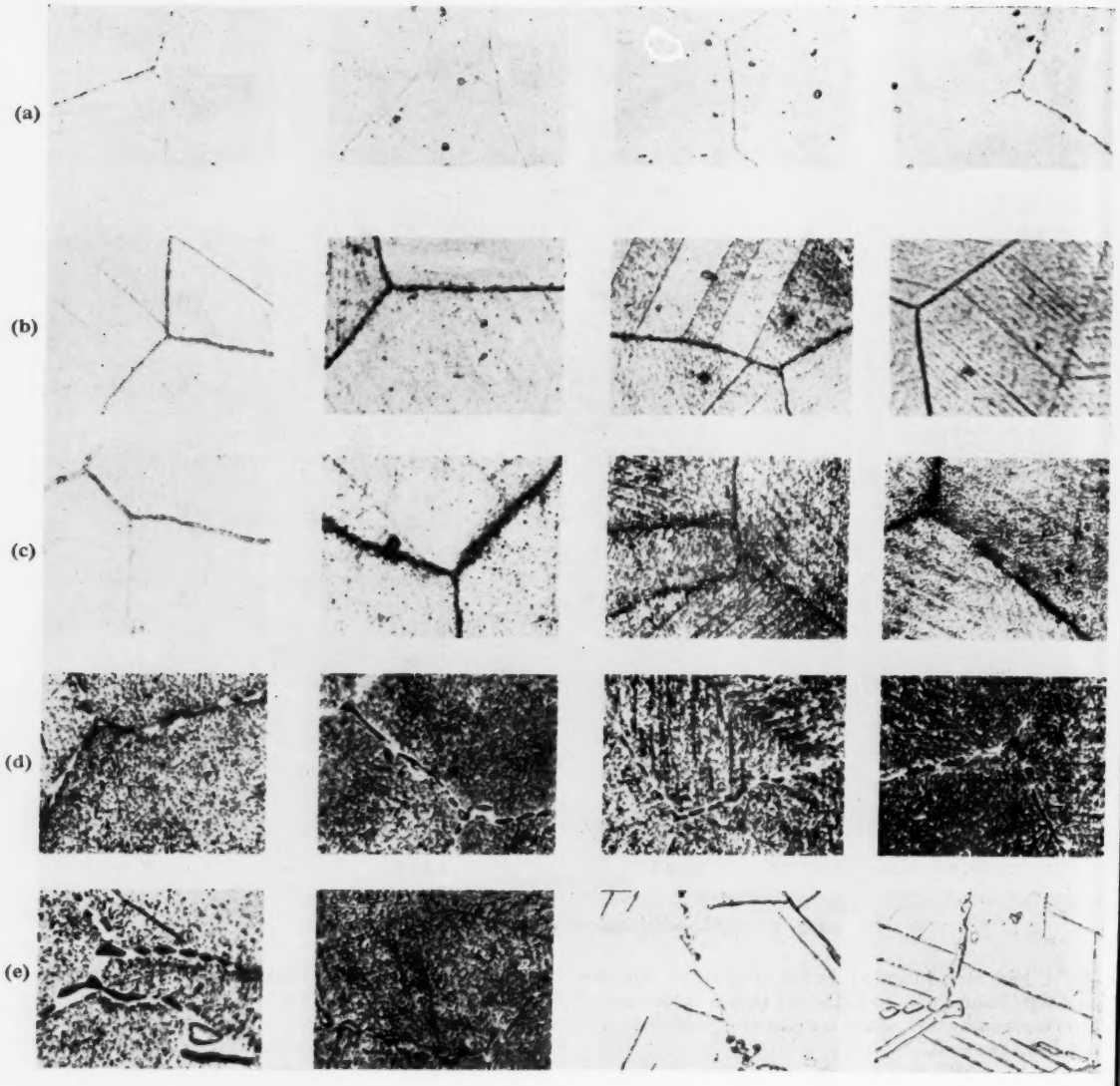

Fig. 2—Microstructures after heat-treatment × 750

Table III and Fig. 1 (solution-treated alloys); the same trend appears in Tables I and II for the lower solution temperatures. It is apparent, however, that an increase in Si content from 0·67% to 2·46% in the higher-C series is insufficient to compensate for the increase of only 0·1% in the C content.

The mode of formation of σ-phase from single-phase austenite or duplex ferrite–austenite structures at 700° and 900° C was fully described in the previous paper, and the essential features have been noted above. The following further observations are made on the basis of the new results:

(i) The previously described modes of formation of σ-phase are fully confirmed

(ii) It appears from Figs. 1 and 2 and from microstructures not illustrated that carbide is precipitated within the grains in a shorter period of time with higher Si content in either of the two C series. In the same way, the approach to equilibrium with regard to the formation of σ is more complete in a given time with higher Si. Hence increasing Si content increases the rate of carbide precipitation and the rate of σ formation, giving a ' diagonal effect ' which was particularly noticeable in the series treated at 700° C, especially after solution at 1250° C (*see* Fig. 2)

(iii) The effect of Si and Ni in raising the maximum temperature of σ formation well above that observed

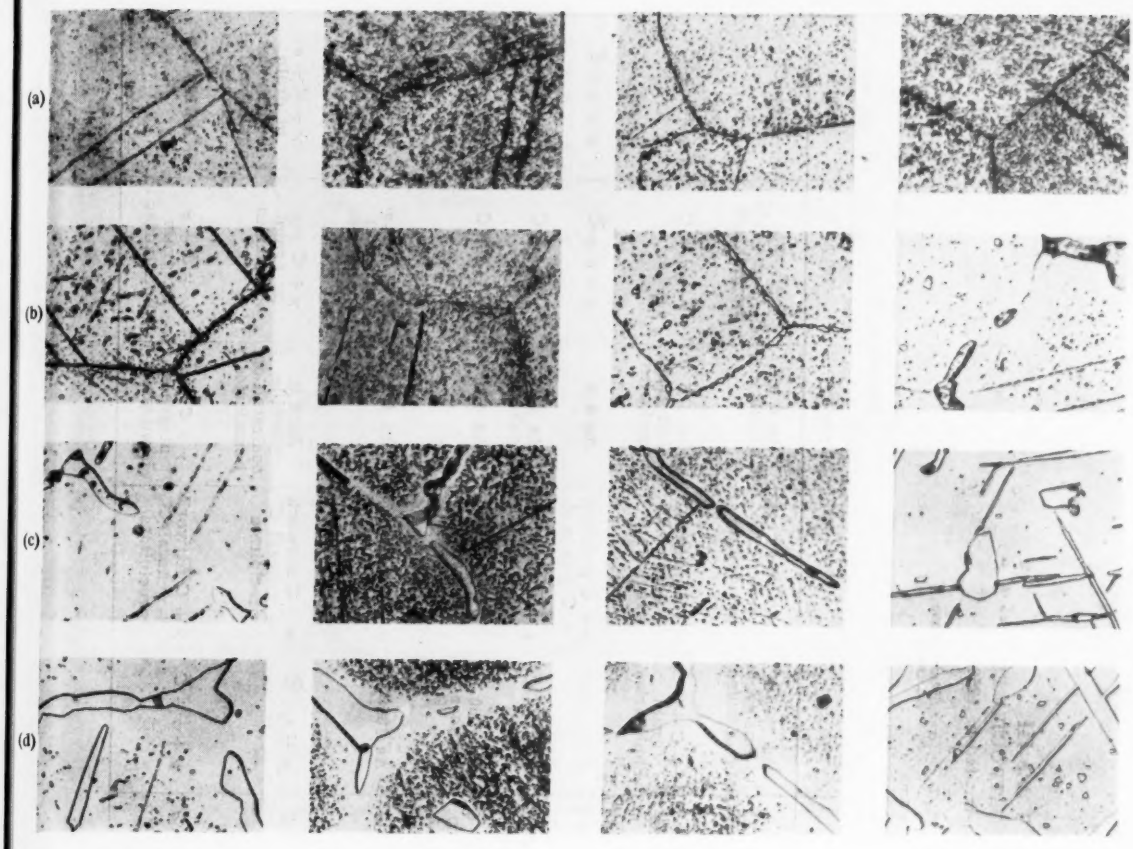

Fig. 2 (contd.)—Microstructures after heat-treatment × 750

in pure Fe–Cr alloys is again supported by the considerable amounts of σ formed at 900° C

(iv) There is some evidence from the microstructures that higher Si gives a larger proportion of σ-phase; this is confirmed by the X-ray work (*see* below).

The results of the X-ray residue analysis are given in Table IV. As stated above, the examination was confined to solution-treated steels and final condition at 700° and 900° C. In view of the very satisfactory way in which the microstructures indicated the initial formation of carbide and the subsequent attainment of equilibrium involving austenite, carbide, and σ, it was not considered essential to examine intermediate alloys. In the previous work, X-ray analysis of ' four-hour ' samples from the steels with a wholly austenitic matrix had confirmed the existence of carbide only and the slower formation of σ under these conditions. In contrast, the steels initially containing ferrite had already shown a considerable transformation to σ in 4 h.

The following points are established or confirmed by reference to the X-ray data in Table IV:

(i) The presence of carbide which is $(Cr,Fe)_{23}C_6$ in all steels solution-treated at 1050° C

(ii) The presence of carbide in the higher-C series at 1150° C

(iii) The complete solution of carbide in the alloys solution-treated at 1250° C was indicated generally by the absence of residues from these specimens. Ferrite was not detected, although it might have been present in some of the alloys

(iv) The relative proportions of σ and carbide in the final condition vary; this is probably partly due to minor segregation effects. In general the proportions of the two phases appear to be similar. No more quantitative estimate is at present possible

(v) The weights of the residues, representing the carbide + σ-phase as a percentage of the steel dissolved, are plotted against Si content in Fig. 3; increasing Si content increases the total bulk of residue and it seems that this is due to an increase in the amounts both of σ-phase and of carbide.

In addition to the identification of the phases, attention was given to whether the σ-phase contained a higher percentage of Si than the mean composition of the steel; the amounts of Si were, however, comparatively small and effects on lattice parameters or interplanar spacings were not very marked. In alloys containing larger amounts of Si, the σ-phase would be expected to undergo lattice-expansion due to solid solution of this element.[3]

Table III
MICROSTRUCTURES
Solution-treated at 1250° C

Key
$\overline{C}$ = Carbide $M_{23}C_6$ σ = Sigma-phase
α = Ferrite γ = Austenite
$\overline{\sigma}$ = Trace of sigma

Steel No.	Solution-treated	Reheated at 700° C					Reheated at 900° C				
		4 h	100 h	1000 h	2000 h	4 h	100 h	200 h	1000 h
5	$\gamma + \overline{C}$ network	$\gamma + \overline{C}$ network	$\gamma + C$ precipitation. Heavy at grain boundaries	As 100 h with more C precipitation	As 1000 h $+\overline{\sigma}$ at grain boundaries	$\gamma + \overline{C}$ network + fine C precipitate	As 4 h (C coalescing)	As 4 h $+\overline{\sigma}$ at grain boundaries	γ + fine $C + \sigma$
6	$\gamma + \overline{C}$ network	$\gamma + C$ network	$\gamma + C$ precipitation. Heavy at grain boundaries	As 100 h $+\overline{\sigma}$ at grain boundaries	$\gamma + C + \sigma$ at grain boundaries	$\gamma + C$ network + general C precipitate	As 4 h $+\overline{\sigma}$ at grain boundaries	$\gamma + \sigma + C$	$\gamma + \sigma + \overline{C}$
7	$\gamma + \alpha + \overline{C}$	$\gamma + (\alpha \rightarrow \sigma) + C$ network + $\overline{C}$	$\gamma + (\alpha \rightarrow \sigma) + C$	$\gamma + (\alpha \rightarrow \sigma) + C$	$\gamma + \sigma + C$	$\gamma + \overline{C}$ network + $C + (\alpha \rightarrow \sigma)$	As 4 h	$\gamma + \sigma + \overline{C}$	$\gamma + \sigma + \overline{C}$
8	$\gamma + \alpha + \overline{C}$	$\gamma + (\alpha \rightarrow \sigma) + C$ network	$\gamma + (\alpha \rightarrow \sigma) + C$ network	$\gamma + (\alpha \rightarrow \sigma) + C$	$\gamma + \sigma + \overline{C}$	$\gamma + \overline{C}$ network + $C + (\alpha \rightarrow \sigma)$	As 4 h (C coalescing)	$\gamma + \sigma + \overline{C}$	$\gamma + \sigma + \overline{C}$
9	$\gamma + \overline{C}$ network	$\gamma + C$ network	$\gamma + C$ network (C coalescing)	$\gamma +$ general C precipitation $+ \sigma$ at grain boundaries	As 1000 h + more σ	$\gamma + C + C$ network (coalescing)	As 4 h	$\gamma + \sigma + C$	$\gamma + \sigma + \overline{C}$
10	$\gamma + \overline{C}$ network	$\gamma + C$ network + C striated	$\gamma +$ heavy C network + C striated	As 100 h $+\overline{\sigma}$	As 1000 h	$\gamma + C$ network + heavy general C precipitate	As 4 h	$\gamma + C + \sigma$ at grain boundaries	$\gamma + C + \sigma$ at grain boundaries
11	$\gamma + \overline{C}$ network	$\gamma + C$ network + C striated	$\gamma + C$ network + C striated	As 100 h $+\overline{\sigma}$	$\gamma + \sigma + \overline{C}$	$\gamma + C$ network + general C precipitate	As 4 h (carbide coalesced on boundaries)	$\gamma + C + \sigma$ at grain boundaries	$\gamma + C + \sigma$ at grain boundaries and cleavage planes
12	$\gamma + \overline{C}$ network	$\gamma + C$ network + C striated	$\gamma + C$ network (coalescing) + C striated	As 100 h $+\overline{\sigma}$	$\gamma + \sigma + \overline{C}$	$\gamma + C$ network + general C precipitate	$\gamma + C + \sigma$ at grain boundaries	$\gamma + \overline{C} + \sigma$ at grain boundaries	As 200 h

The hardness measurements and bend tests should be consistent with the observed changes in structure; that this is generally so can be seen by reference to Figs. 4 and 5, in connection with which the following observations are made:

(i) There is not a great difference in hardness between the low- and high-C series, so that an increase in the amount of carbide does not appreciably affect the hardness. There is a tendency, however, for the higher-C steels to be slightly harder

(ii) There is a definite increase in hardness with Si content in each series, and this must be mainly due to increasing amounts of σ-phase in accordance with Fig. 3 and the microstructures. There may be slight solid-solution hardening as suggested by the solution-treated alloys, but this is not definite

(iii) The bend tests reveal that an increase in hardness is generally accompanied by a decrease in ductility

(iv) For the 100-h samples, the general trend is that, even in this period of time at temperature, there is no great loss of ductility. There is a tendency to lower ductility with higher Si in this time at either 700° or 900° C

(v) There is evidence that some embrittlement is caused by carbide, since the higher-C steels are generally less ductile in the 100-h condition

(vi) After 1000 h at 700° and 900° C, the fall in ductility, as indicated by the lower angle of bend, is considerable

(vii) It appears that 1000 h at 700° C does not give a seriously brittle condition with the lower Si content. The dependence upon Si is rather more marked here. This may, however, derive from the fact that σ formation has not proceeded to completion at 1000 h with

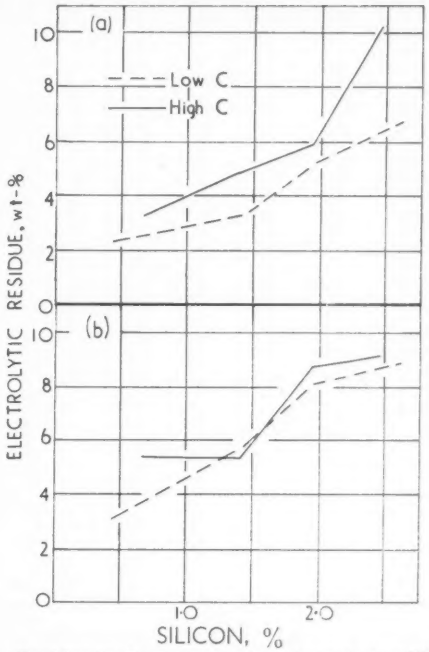

Fig. 3—Residue for X-ray analysis: reheated at (*a*) 700° C, (*b*) 900° C

Table IV

X-RAY RESIDUE ANALYSES

Phases Present and Relative Proportions in Residue

***Notes*:** Percentage of residue in brackets. Traces of oxides occasionally present in addition to *C* or σ (also α, or γ solid solution)
***Key*:** *C* = Carbide $M_{23}C_6$ σ = Sigma-phase. Approx. amounts l = large m = medium s = small tr. = trace ml = medium large ms = medium small. An attempt is also made to indicate doubtful estimates, e.g. 'between m and ml' is given by m+

Steel No.	Solution-treatment 1050° C			Solution-treatment 1150° C			Solution-treatment 1250° C		
	Solution-treated	2000 h 700° C	1000 h 900° C	Solution-treated	2000 h 700° C	1000 h 900° C	Solution-treated	2000 h 700° C	1000 h 900° C
5	*C*, l	*C*, s; σ, l	*C*, sm; σ, ml	*	*C*, l; σ, s	*C*, m; σ, s/m	*	*C*, m; σ, m (2·34%)	*C*, l; σ, s (3·10%)
6	*C*, l	*C*, m; σ, ml	*C*, m; σ, m	*	*C*, m−; σ, m+	*C*, m; σ, m	*	*C*, m; σ, m (3·32%)	*C*, m; σ, m (5·79%)
7	*C*, l; α tr.	*C*, m; σ, m	*C*, m−; σ, l	*	*C*, m−; σ, m+	*C*, m−; σ, m+	*	*C*, m−; σ, m+ (5·16%)	*C*, m; σ, m (8·10%)
8	*C*, l; α s	*C*, m−; σ, m+	*C*, m−; σ, m+	*	*C*, m; σ, m	*C*, m; σ, m	*	*C*, m; σ, m (6·75%)	*C*, m; σ, m (8·90%)
9	*C*, l	*C*, ms; σ, l−	*C*, s+; σ, l	*	*C*, m; σ, m	*C*, tr; σ, l	*	*C*, m+; σ, m− (3·27%)	*C*, m; σ, m (5·37%)
10	*C*, l	*C*, m+; σ, m−	*C*, m; σ, m	*C*, l	*C*, m+; σ, m−	*C*, m; σ, m	(γ)	*C*, m+; σ, m− (4·87%)	*C*, m; σ, m− (5·32%)
11	*C*, l	*C*, m−; σ, m+	*C*, m−; σ, m+	*C*, l	*C*, m; σ, m	*C*, m−; σ, m+	(γ)	*C*, m+; σ, m− (5·95%)	*C*, m; σ, m (8·73%)
12	*C*, l	*C*, l−; σ, s+	*C*, m−; σ, m+	*C*, m ($+\gamma$, ml)	*C*, m; σ, m	*C*, m; σ, m	(γ)	*C*, m; σ, m (10·24%)	*C*, m−; σ, m (9·13%)

* No residue

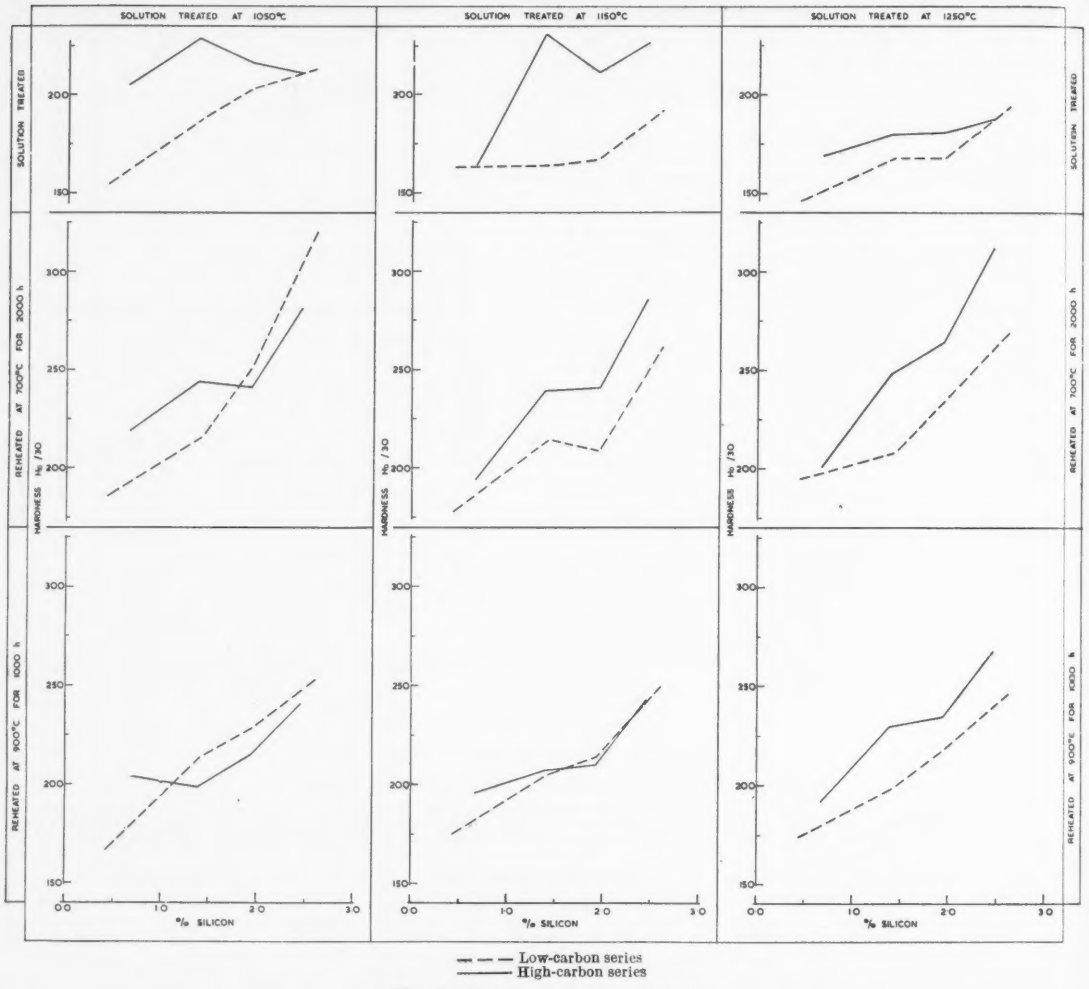

Fig. 4—Hardness measurements

lower Si but is more nearly complete with the higher Si. At 900° C the trend with Si is less clear and bend angles are lower, due to the more developed condition of σ formation.

These observations show that the mechanical properties can be explained by reference to the development of σ-phase, a conclusion in accordance with much published work on the effects of σ-phase.[4, 5] The effect of Si on these properties derives from the influence of this element on the development of σ; the hardness and bend test results are thus consistent with the microstructural results. The effect of carbide on these properties is apparently not very pronounced at these temperatures. Age-hardening effects due to carbide precipitation could probably be produced at lower temperatures.

DISCUSSION OF RESULTS

The results provide considerable information on the effect of Si and amplify the conclusions of the previous paper with regard to the effect of C. The conclusions are, in general, consistent with the observations of other workers dealing with Cr–Ni steels in the σ-forming ranges of composition. Increasing C tends to promote a wholly austenitic condition at solution temperatures, and increasing Si has the reverse effect, favouring the duplex condition. The mode of formation of σ depends on this prior condition.

In the previous paper, reference was made to a formula of Gow and Harder, who stated that steels in this class contained σ-phase after 48 h at 870° C, if (Cr − 16C)/Ni was not less than 1·7. This formula applied to steels containing some Mn and Si; the ratio 1·7 represents, however, the dividing line between the two types of σ formation, since σ ultimately forms in steels for which the ratio is less than 1·7, but it then forms from a wholly austenite matrix. The ratio is effectively one of modified Cr content to modified Ni content. In the system Fe–Cr–Ni (no Mn, C, or Si) the ratio would be about 1·5. A direction corresponding to this ratio would be nearly parallel to the phase boundaries (*see* below and Fig. 6), but it would be more correct to use the phase boundary for alloys in

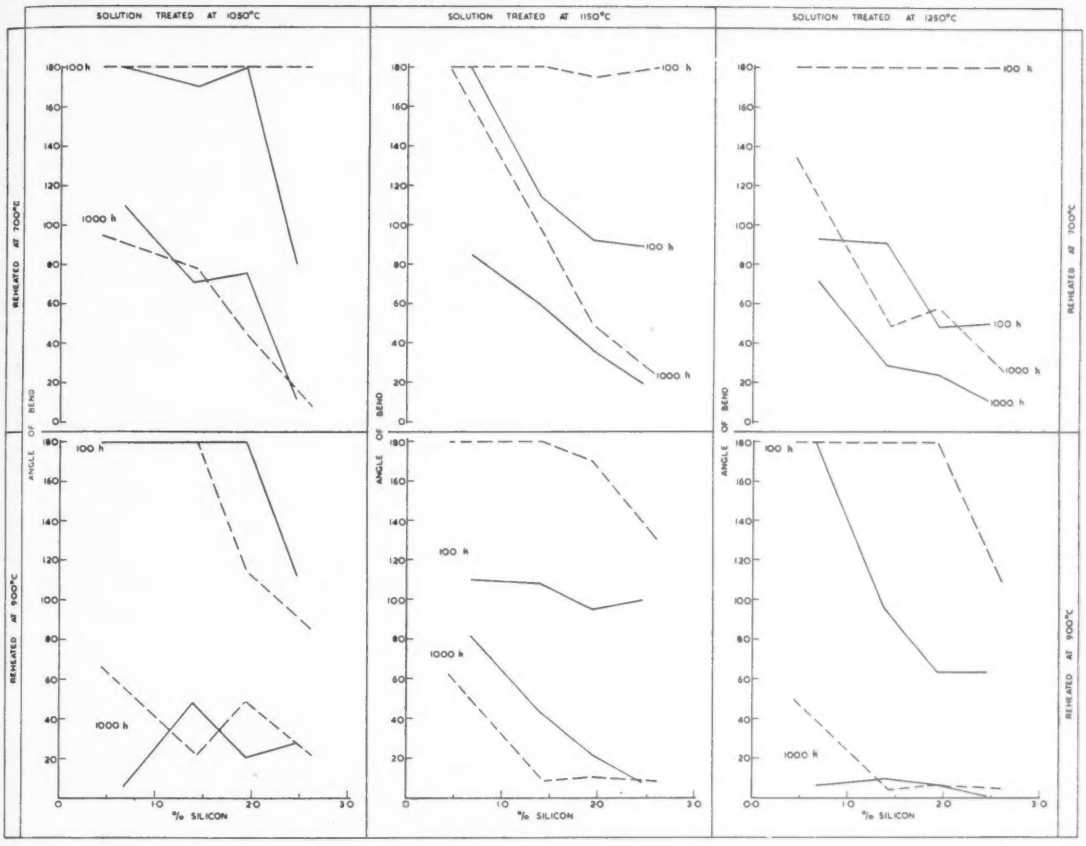

Fig. 5—Bend tests

Table V
EQUIVALENT OR EFFECTIVE COMPOSITIONS AND RATIOS

Steel No.	For Solution-treated Condition*			For Precipitated Condition†		Gow and Harder's Ratio‡
	Cr′	Ni′	Cr′/Ni′	Cr′	Ni′	
1	29·99	17·29	1·73	29·63	16·66	1·73
2	30·57	18·00	1·70	29·85	16·74	1·73
3	30·48	20·06	1·52	28·56	16·70	1·61
4	30·28	22·11	1·37	27·17	16·66	1·50
5	25·96	18·82	1·38	24·88	16·92	1·40
6	29·05	19·01	1·53	27·86	16·91	1·61
7	30·34	19·02	1·59	29·15	16·92	1·68
8	32·73	18·92	1·73	31·65	17·04	1·85
9	26·73	21·00	1·27	24·45	17·01	1·34
10	28·97	21·02	1·38	26·70	17·03	1·49
11	30·28	21·46	1·41	27·77	17·05	1·56
12	32·10	20·99	1·53	29·82	16·99	1·71

* Equivalent Cr = Cr + 3 Si; equivalent Ni = Ni + 1·5 Mn + 21C
† Equivalent Cr = Cr + 3 Si − 12 (C − 0·03); equivalent Ni = Ni + 1·5 Mn + 0·63
‡ $\frac{Cr - 16\,C}{Ni}$ modified to allow for Si in excess of 1%

i.e. $\frac{Cr - 16\,C + 3\,(Si - 1)}{Ni}$

this region and to take an 'equivalent Cr content,' Cr′ and 'equivalent Ni,' Ni′.

The following approach is believed to give a close representation of the structures obtained:

(i) For the solution-treated condition:

$$\left.\begin{aligned} Cr' &= Cr + 3\,Si \\ Ni' &= Ni + 1{\cdot}5\,Mn + 21\,C \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots(1)$$

The factor of 3 for Si is the same as was used previously. That Si has a marked effect in promoting σ formation is supported by the work of Morley and Kirkby.[6] A factor for Mn was not previously given, but Gow and Harder had suggested a factor of only $\frac{1}{3}$; this is thought to be much too low. From recent work in the authors' laboratories, it appears that a factor of about 1·5 would apply for small amounts of Mn but more certainly in low-alloy steels[7] and this factor is adopted tentatively here. The factor for C reflects its strong austenite-forming capacity. In Fig. 6 a part of the system Fe–Cr–Ni is illustrated; this diagram shows the effective or equivalent compositions corresponding to the original series of steels with increasing C content, and the new series of steels divided into two groups with increasing Si content. Approximate phase boundaries for 1050°, 1150°, and 1250° C, based on a study of the best published data available, are shown on this diagram. The line

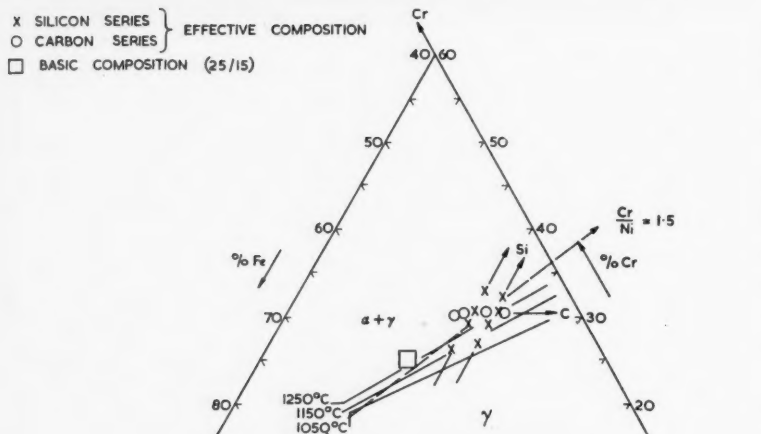

Fig. 6—Equivalent composition for solution-treated steels

corresponding to Cr/Ni = 1·5 is also shown. For practical purposes the phase boundaries can be regarded as corresponding to a single line represented by the approximate formula

$$Cr' = Ni' + 8 \quad \ldots\ldots(2)$$

as long as Ni′ lies between about 13 and 25 wt-%. This line is not parallel to Cr/Ni = 1·5 but is near to it in the range of composition studied. The equivalent compositions for the 12 steels used in this diagram are given in Table V together with values of the ratio. The dividing line given by this ratio at about 1·5 or by Gow and Harder's ratio (last column in Table V) at 1·7, is approximately correct. Steel 12 would be a borderline case and traces of ferrite, found at 1050° and 1150° C, were thought to be due to segregation. Steel 6 is another borderline case, but traces of ferrite were not reported. Although either ratio is approximately correct, it is thought that the rule Cr′ = Ni′ + 8 is more satisfactory and will apply over a wider range.

(ii) For the precipitated alloys, most of the C (except about 0·03%) is now present as $(Cr,Fe)_{23}C_6$:

$$\left.\begin{aligned} Cr' &= Cr + 3\,Si - 12\,(C - 0{\cdot}03) \\ Ni' &= Ni + 1{\cdot}5\,Mn + 21 \times 0{\cdot}03 \end{aligned}\right\} \quad (3)$$

When these equivalent compositions (*see* also Table V) are plotted in the Fe–Cr–Ni triangle as in Fig. 7, they give points lying nearly in a single line in which Si acts in the reverse direction to C. (In all the steels the actual Cr and Ni contents are very similar.)

In Fig. 7 the phase boundaries are shown for the equilibrium of γ with σ. It is apparent that the boundary for 900° C, as based on published information, is probably not correct for ultimate equilibrium, since this takes exceptionally long periods to reach in the steels on the low Cr side of the line; hence for long periods of service at 900° C, the second boundary is shown. This line is given by

$$Cr' = 17{\cdot}16 + 0{\cdot}37\,Ni' \quad \ldots(4)$$

For precipitation at lower temperatures (e.g. 700° C), however, considerably lower Cr content is required (Cr down to 18%) to avoid σ formation.

An indication of the use of the above formulæ can be given; in the steels examined here, the base composition was 25% Cr, 15% Ni, and, with 0·2% C and 1% Mn, the relationships (1) and (2) give

$$\begin{aligned} Ni' &= 20{\cdot}7 \\ \therefore Cr' &= Ni' + 8 = 28{\cdot}7 \\ &= 25 + 3\,Si \\ \therefore Si &= 1{\cdot}2\% \end{aligned}$$

The Si content must, therefore, be less than 1·2% if the partly ferritic condition is to be avoided; alternatively, with Ni = 16% the Si level should not be raised above 1·6%.

To avoid σ formation at 900° C the condition to be observed is that

$$Cr' < 17{\cdot}16 + 0{\cdot}37\,Ni' \text{ (derived from (4))}$$

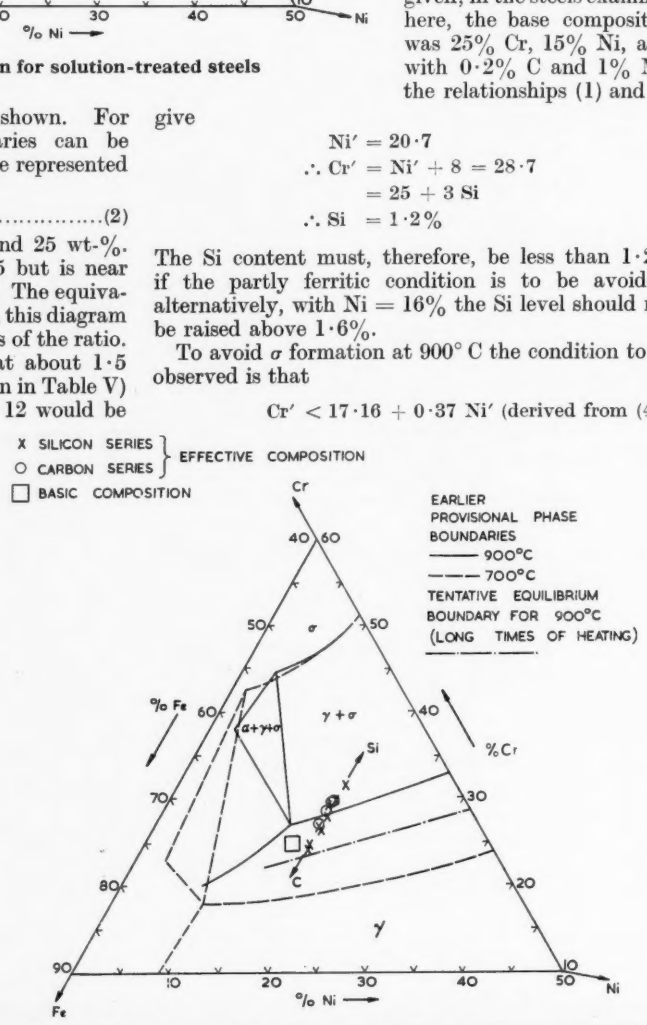

Fig. 7—Equivalent composition for precipitation of sigma (and carbide)

From (3) $Ni' = Ni + 1{\cdot}5\,Mn + 21 \times 0{\cdot}03$
$= 17{\cdot}13$
$Cr' = Cr + 3\,Si - 12\,(C - 0{\cdot}03)$
$= 22{\cdot}96 + 3\,Si$
$22{\cdot}96 + 3\,Si < 17{\cdot}16 + 6{\cdot}34$
$< 23{\cdot}50$
$3\,Si < 0{\cdot}54$

The Si content must not exceed 0·18% and, if this rather stringent condition is to be avoided, the Ni and/or Mn content must be raised.

From the results obtained with the hardness and bend tests, however, it does not necessarily follow that a completely σ-free condition need be stipulated to retain a desirable degree of ductility. Although σ-phase was formed in all the steels examined, it is noteworthy that with lower Si content the rate of formation is lower and the amount formed is less. Consequently, provided that the Si content is kept towards the lower limit of the range studied, long periods of heating are necessary before the ductility is seriously reduced. Reference to the microstructures suggests that a fine dispersion of σ particles may in fact be advantageous in producing some hardening without appreciable loss in ductility. On the other hand, when the σ particles have grown into a more massive form after long periods of heating, there results a more serious loss of ductility. The time taken to achieve this condition is obviously shorter at higher temperatures.

CONCLUSIONS

(1) The mechanism and mode of formation of σ-phase in a 25% Cr, 15% Ni steel, as described in a previous paper, have been further confirmed and extended, particularly in regard to the influence of the C content. The new work establishes the pronounced effect of Si on the formation of σ by increasing both the amount of the phase and its speed of formation.

(2) The difference between steels which are wholly austenitic at solution temperatures and those which are partly ferritic is again apparent; σ forms much more rapidly in the latter case. Formation from an austenite matrix proceeds after precipitation of carbide and to some extent replaces this constituent after long periods of heating. The mechanism of the process was discussed in the earlier paper.

(3) The results and observations have been closely related to the relevant region of the phase diagram for the system Fe–Cr–Ni, and reference is made to the approximate formula given by Gow and Harder; this formula essentially corresponds to a constant ratio of equivalent Cr content to equivalent Ni content. It is demonstrated that it differentiates approximately between alloys which are austenitic at solution temperatures and those which are partly ferritic, i.e. between the two modes of σ formation.

(4) An improved formula is given, by means of which the composition of steels of this type can be adjusted to give the fully austenitic condition at solution temperatures. Thus with Cr 25%, Ni 15%, Mn 1%, C 0·2%, Si should be less than 1·2% to give the austenitic condition; a similar formula enables compositions to be chosen which will be free of σ formation at 900° C even after prolonged heating. At lower temperatures, considerably lower Cr content would be necessary to avoid σ formation altogether; an alternative would be to raise the Ni content, but by itself this would not be as effective.

(5) Hardness and bend tests are in accord with the constitution as shown by microscopical and X-ray examinations. The effect of Si in increasing the amount of σ and its rate of formation is reflected in the trend towards a smaller angle of bend with higher Si content. One important point is that the lowest ductility is usually reached only with prolonged heating at temperature, associated with the presence of large σ grains. In most cases, for example, heating for 100 h at 700° or 900° C results in no serious loss of ductility, although there is a falling off towards higher Si content. It follows that it is not essential to insist upon a σ-free condition for every kind of service, since the effects of this constituent are dependent on the size and distribution of particles, which in their turn depend on composition, time, and temperature of heating.

Acknowledgments

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The Determination of the Alpha Phase Boundaries of the Iron–Nitrogen System by Internal Friction Methods

By

R. Rawlings, B.Sc., A.I.M., and D. Tambini, B.Sc.

SYNOPSIS

The solubility of Fe_4N in iron has been determined using the internal friction method. Equilibrium was approached by nitriding for comparison with the results obtained by precipitation by Dijkstra. The agreement was good. The $\alpha/\alpha + \gamma$ boundary was also determined using internal friction methods. The results are slightly lower than those obtained by Paranjpe *et al.*, who used a gas-metal equilibrium method. An expression has been obtained for the internal friction due to interstitial elements of a quasi-isotropic aggregate of crystals assuming the corresponding expression by Polder for a single crystal. 1161

THE IRON–NITROGEN SYSTEM may be considered fairly well established by Paranjpe *et al.*[1] and previous workers. The present work is concerned with the boundary of the α-area only, since this is the part of most importance in steel, particularly in regard to strain-ageing and the difference in properties between Bessemer and open-hearth steels. Only recent work will be reviewed, as Paranjpe *et al.* have adequately covered previous work. However, a summary is given in Table I of the determination of the maximum solubility at the eutectoid.

The $\alpha/\alpha + \gamma$ Boundary

The only recent work is by Paranjpe who determined the nitrogen content at 650° and 700° C. These points are shown in Fig. 1.

The α/α + Fe_4N Boundary

The results of Paranjpe *et al.*[1] are shown in Fig. 1 together with those of Dijkstra.[6] Paranjpe attempted to explain the discrepancies between his results and Dijkstra's by suggesting: (*a*) that the latter obtained low results at the higher temperatures because of precipitation before measuring the internal friction, and (*b*) that at low temperature his results were high because of incomplete precipitation. At first the explanation seems quite feasible. With the higher amounts of nitrogen in solid solution, precipitation is indeed faster as Dijkstra's own results show. On the other hand, he used a small specimen, namely, 0·03 in. dia., so that the cooling rate during quenching was very high. Again, it is true that, at lower temperatures, precipitation is more likely to be incomplete; but Dijkstra's results differ significantly even at a temperature of 500° C when precipitation is comparatively fast. One weakness in Dijkstra's results was that he relied on a correlation between internal friction and nitrogen which he appears to have checked only up to 0·015%N. For this reason, the present authors undertook to determine the internal friction at higher nitrogen contents. The results of these experiments are published elsewhere.[8] Previously, Borelius and Åström[7, 9] had carried out similar experiments differing from others reported,[8] but agreeing in that the internal friction for a given nitrogen content was significantly less than was previously thought. Additional evidence based on theoretical grounds for the correlation found is given in the Appendix. Using our experimental results (N% by weight in solid solution = 1·28 × internal friction peak at 17° C), Dijkstra's results have been replotted in Fig. 2. Simultaneously, Fast and Verrijp[22] published a very similar result, namely, N% = 1·26 × internal friction peak at 22° C.

Åström also determined the solubility of nitrogen both by an anelastic method and by a calorimetric method. His results shown in Fig. 2 agree fairly closely with those of Dijkstra's at the higher temperatures. In order to decide between the two sets of results it was resolved to redetermine the boundary using internal friction methods. Instead of the precipitation technique used by Dijkstra it was thought

Table I

EUTECTOID TEMPERATURE AND MAXIMUM NITROGEN CONTENT OF ALPHA IRON AT THE EUTECTOID TEMPERATURE

Year	Authors	Eutectoid Temperature, °C	Max. nitrogen content of iron at the eut. temp., wt-%
1923	Fry[2]	580	0·5
1930	Eisenhut and Kamp[3] ...	591	0·42
1930	Lehrer[4]	591	0·40
1935	Portevin and Séférian[5]	590	0·13
1949	Dijkstra[6]...	Not det.	0·085 at 590°C
1950	Paranjpe *et al.*[1] ...	Not det.	0·10 at 590°C

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desirable to approach equilibrium from below, i.e. by nitriding a specimen initially containing little or no nitrogen.

Apparatus

It is well known that most of the iron–nitrogen system is metastable (e.g. α-iron contains only 0·004%N under 1 atm of nitrogen at a temperature of 900° C). Higher nitrogen-containing alloys can be prepared by making use of the reaction

$$2NH_3 = 2[N] + 3H_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

which takes place, under streaming conditions, in preference to the reaction

$$2NH_3 = N_2 + 3H_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

There is probably also a similar reaction for hydrogen in iron

$$2NH_3 = N_2 + 6[H] \quad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Like nitrogen, hydrogen dissolves interstitially but its internal friction peak is small and occurs at − 170° C.[13] Dijkstra[6] showed that there was no measurable internal friction due to hydrogen at room temperature, at which the present series of results were carried out.

Previous workers have obtained their ammonia–hydrogen atmospheres by mixing the two gases. In these experiments ammonia only was used. The ammonia was led through a heated steel tube, a flowmeter, and then to a silica tube in the nitriding furnace. The ammonia was partially cracked (reaction (2)) in the steel tube, the degree of dissociation depending on the temperature of the steel tube (called the 'cracker') and the rate of gas flow. The temperature was controlled automatically while the flow was satisfactorily controlled manually. No determinations of ammonia were made, as preliminary experiments showed that the ammonia entering the nitriding furnace was greater than that leaving it, owing to a slight dissociation according to reaction (2). The ammonia content as determined would thus have no great significance, hence the controlled temperature of the cracker furnace was used as a measure of the degree of dissociation. The flow of gas used was approximately 100 ml/min. The temperature of the nitriding furnace was automatically controlled using a chromel–alumel thermocouple. The temperature zone in the nitriding furnace was uniform (± 3° C) over the length of the specimen.

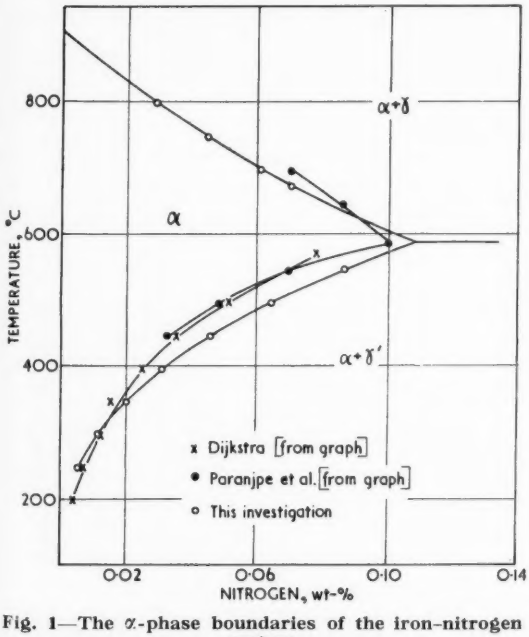


Fig. 1—The α-phase boundaries of the iron–nitrogen system

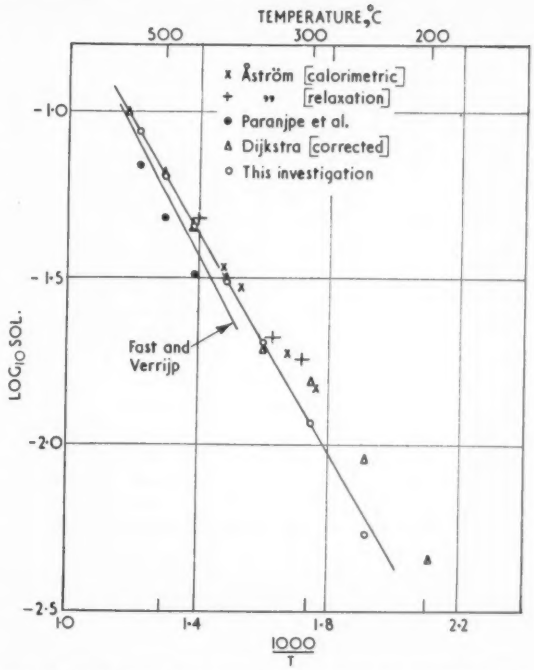


Fig. 2—The nitrogen content of α-iron in equilibrium with Fe_4N

The internal friction apparatus was similar to that of Kê[10] as modified by Fine[11] to facilitate starting of the pendulum. A specimen only 2 in. in length was used to obtain a more uniform temperature distribution. The period of vibration was adjusted to about 1·8 s in order that the internal friction peak should occur at 17° C. Variation in specimen temperature was obtained by passing tap water through a copper coil surrounding the specimen. This was found adequate to cool the specimen from room temperature to about 12° C. This arrangement enabled very rapid determinations to be made of the internal friction peak, thus reducing the possibility of precipitation of any nitride before testing. The temperature of the specimen was, of course, very uniform, being almost the same as room temperature. The background damping was 0·0007, obtained by annealing a specimen for long periods in hydrogen. The amplitude of vibration varied from 1 to 4 cm at 1 m, corresponding to a shear strain of from 5×10^{-5} to 2×10^{-4}. Only amplitudes giving a linear relationship between log amplitude and number of swings were used, i.e. the internal friction was

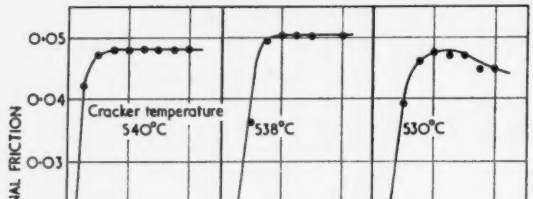


Fig. 3—Nitriding curves at 500° C

independent of strain amplitude. The maximum strain for this condition was found to increase with nitrogen content, possibly owing to a general stiffening of the lattice. However, no quantitative investigation was made. No magnetic field was used to suppress magneto-mechanical effects as they appeared to be negligible. The actual measurement of the internal friction could be reproduced to $\pm 0{\cdot}0002$.

Material

The material used as supplied by B.I.S.R.A.* in the form of a bar 2 in. × 2 in. Although the oxygen content of this iron is high, the concentration in solution is probably too small[21] to affect the solubility of Fe_4N. For the same reason (apart from the fact that it may be dissolved substitutionally), it is unlikely to cause internal friction effects. The bar was hot-forged and rolled to $\frac{1}{4}$-in. dia. rod. This rod was then cold-drawn to $\frac{1}{16}$-in. dia. wire, annealed in hydrogen at 950° C, and finally drawn to 0·020 in. dia.

The wire specimens 0·020 in. dia. × 4 in. long (only 2 in. of which were actually tested) were heated for 15 min at 950° C in wet hydrogen to remove traces of carbon and nitrogen present and to remove any ⟨110⟩ texture resulting from the cold drawing. When tested, the specimens showed no trace of the internal friction peaks due to carbon or nitrogen, the background damping being only 0·0007. The ⟨110⟩ texture is not removed by annealing at temperatures up to 800° C,[23] but was presumed to be removed on recrystallization at the A_3 temperature. This has since been confirmed by Fast and Verrijp.[24]

After the annealing treatment the specimens were quenched in water in order to give a fine-grained structure specimen, as it had been found that any other method of cooling resulted in coarse grain structure which was to be avoided as being liable to give a non-random aggregate orientation.

DETERMINATION OF SOLUBILITY OF Fe_4N IN IRON

At 250°, 300°, and 400° C a single iron wire specimen was nitrided until the internal friction no longer increased with increasing ammonia content of the atmosphere. At 450°, 500°, and 550° C, a new wire specimen was nitrided for each different ammonia atmosphere. The result of nitriding at these higher temperatures was interesting.

Figure 3 shows typical nitriding curves for increasing ammonia contents in the gas. In curves 1 and 2 a limit to the internal friction is reached, whereas curve 3 shows a fall with increasing times. Microscopic examination showed the fall to be associated with the formation of a case of Fe_4N.

The variation of highest internal friction observed with the ammonia content of the nitriding atmosphere is shown in Fig. 4 for nitriding temperatures of 450°, 500°, and 550° C. The maximum value of the internal friction at each temperature corresponds to a saturated solid solution. Table II gives the maximum internal friction at each temperature by nitriding, the corresponding calculated nitrogen content, and the minimum internal friction by precipitation.

The maximum internal friction at a few temperatures was also determined by precipitation experiments. Iron-wire specimens were loaded with nitrogen and the excess was precipitated at the temperature under test.

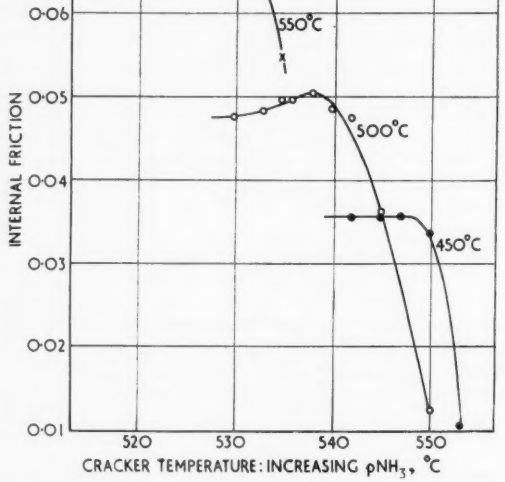


Fig. 4—Variation of internal friction with cracker temperature

* B.I.S.R.A. Mark A.G.B.1. Typical analysis 0·004% C, 0·002% Si, 0·004% S. 0·28% O, 0·01% N.

Table II

NITROGEN CONTENTS OF SATURATED α-IRON BELOW THE EUTECTOID

Temp., °C	Internal Friction Peak Nitriding	N, % wt. Ni, % by calc. ($1{\cdot}28Q^{-1}$ max.)	Internal Friction Peak Precipitation
250	0·0042	0·0054	—
300	0·0090	0·0115	0·0089
350	0·0156	0·0200	0·0155
400	0·0240	0·0310	0·0242
450	0·0354	0·0453	0·0353
500	0·0505	0·0646	—
550	0·0680	0·0870	—

The course of precipitation was followed by internal friction measurements until equilibrium was attained. Precipitation and nitriding curves are shown in Fig. 5. The equilibrium internal friction values agree closely with those obtained by Dijkstra, and with the internal friction values obtained by nitriding.

DETERMINATION OF THE $\alpha/\alpha + \gamma$ PHASE BOUNDARY

The method is described in relation to the determination at 700° C. Preliminary experiments had shown that the maximum internal friction corresponding to a saturated solid solution at 700° C was much lower than the 0·07%N by weight found by Paranjpe *et al.* for the solubility at 700° C.

Two specimens of pure-iron wire, *A*20 and *A*21, were nitrided at 650° C in an atmosphere of ammonia cracked at 605° C. The final internal friction readings were 0·051 and 0·0620 respectively. After annealing at 700° C for ½ min the internal friction of *A*20 was 0·0413, and that of *A*21 was 0·0390.

It was difficult to understand why the wire having the lower internal friction originally should give the higher internal friction after the heat-treatment at 700° C. Wire *A*21 was sectioned and examined microscopically. The structure was composed of a thin martensitic case and a central core of α-phase containing small isolated grains having a troostitic pearlite and martensitic structure. The nitrogen in excess of that soluble in α-Fe at 700° C has thus formed γ-phase, which transformed to martensite on quenching.

The martensite case explains why the internal friction of *A*20 was higher than that of *A*21 after heat treatment at 700° C. *A*21 contained more nitrogen originally and so had a greater excess of nitrogen at 700° C; this gave rise to a thicker case of martensite than in *A*20. Martensite does not contribute to the internal friction so the effective internal friction of *A*20 was greater than that of *A*21.

To determine the internal friction due to a completely saturated solid solution at 700° C, wire *A*20 was subjected to a series of heat-treatments of ½ min each at 700° C. The atmosphere was such that the excess nitrogen present in the case of α-phase diffused out of the specimen. As the case disappeared, the internal friction increased to a maximum, then

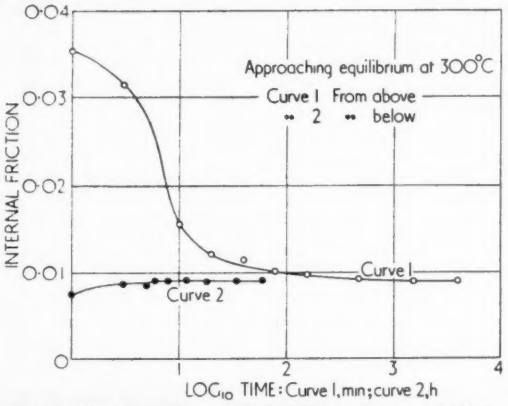


Fig. 5—Precipitation and nitriding curves at 300° C

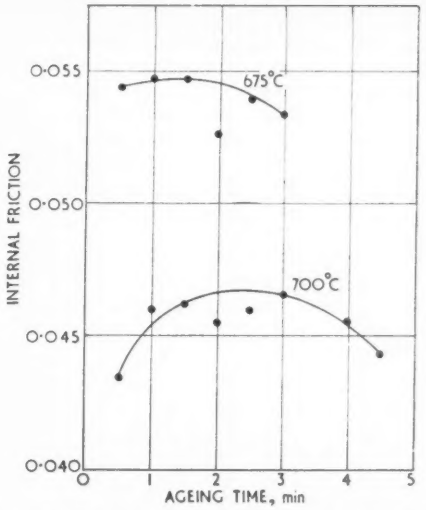


Fig. 6—Determination of solubility of nitrogen at 675° C and 700° C

decreased on further heat-treatment as nitrogen was lost from the saturated solid solution. After the last heat-treatment *A*20 was sectioned and examined under the microscope. No martensite was observed.

The determination at 700° C was repeated, and the method extended to other temperatures. The variation of internal friction with time of heat-treatment for *A*25 at 700° C, and *A*29 at 675° C, is shown in Fig. 6, the maximum corresponding to when the wire was wholly saturated solid solution. The maximum internal friction at each temperature, and corresponding nitrogen content, are given in Table III. The $\alpha/\alpha + \gamma$ phase boundary is shown in Fig. 1.

DISCUSSION

The accuracy of the results depends directly on the relation between the internal friction peak and nitrogen content in solution. The relation found by the present authors[8] differs considerably from that of Åström and Borelius.[7, 9] Using the latter's figures, the maximum nitrogen content at the eutectoid temperature becomes about 0·2%N using the extrapolated solubility results of Dijkstra and present work. This disagrees with the calorimetric determinations of Åström[7] and the $\alpha/\alpha + Fe_4N$ boundary as determined by Paranjpe[1] and by present work. This is an additional reason for preferring the straight-line relationship to the curved relationship between internal friction and nitrogen content.

Table III

NITROGEN CONTENT OF α-IRON AT THE $\alpha/\alpha+\gamma$ BOUNDARY

Temp., °C	Internal Friction Peak	Nitrogen %, By Calculation (= $1 \cdot 28Q^{-1}$ max.)
675	0·0548	0·0701
700	0·0472	
	0·0467	0·0605
750	0·0346	0·0443
800	0·0224	0·0286

Solubility of Fe_4N

The present results agree almost exactly with those of Dijkstra except that at 300° C and at 250° C the latter are higher. No direct evidence is offered that the present results for the low temperatures refer to equilibrium with Fe_4N and not with Fe_8N. However, since the solubility of Fe_8N is so much higher than that of Fe_4N, and since Dijkstra's solubility measurements for Fe_4N are higher than the present ones, then the latter are assumed to refer to Fe_4N. In a plot of log N against $1/T$ the present results fall very nearly on a straight line. It seems possible that the higher results of Dijkstra correspond to incomplete precipitation. The equation to the straight line best fitting the results is

$$\log \text{N (sol./Fe}_4\text{N)} = \frac{-1649}{T} + 0{\cdot}942 \ldots\ldots\ldots\ldots (4)$$

giving a heat of solution of Fe_4N of 7540 cal/mol Fe_4N over the range 300–550° C.

The corresponding equation given by Fast and Verrijp[24] is

$$\log \text{N (Fe}_4\text{N)} = \frac{-1814}{T} + 1{\cdot}09 \ldots\ldots\ldots\ldots (5)$$

over the temperature range 380–580° C and from the results of Paranjpe *et al.*[1] we obtain

$$\log \text{N (Fe}_4\text{N)} = \frac{-1960}{T} + 1{\cdot}20 \ldots\ldots\ldots\ldots (6)$$

over the temperature range 450–550° C corresponding to heat of solution of 7540, 8300, 8960 cal/g-mol Fe_4N respectively. Dijkstra's results yield a figure of 7700 cal/mol Fe_4N. The heat of solution derived from the results of Paranjpe *et al.* appears to be in error, possibly owing to the small temperature interval used.

At the eutectoid temperature (taken to be 590° C—*see* Table I), the solubility according to Fast and Verrijp is 0·097%N, while the present results give a value of 0·108%. The one determination by Corney and Turkdogan[25] at 605° C of the $\alpha/\alpha + \gamma$ boundary as being at 0·10%N agrees exactly with the present results and suggests that the results of Fast and Verrijp may be slightly low.

On the other hand, Corney and Turkdogan determined the solubility of Fe_4N in α-iron at 502° C as being 0·060%N. This again is higher than Fast and Verrijp's value of 0·0565%N, but is lower than that of 0·0645%N found in the present work. The corresponding value by Paranjpe *et al.* is 0·049%N. Åström did not report a measurement for 500° C, but at 400° C, using a calorimetric method, he obtained a value slightly higher than that given by the present results.

It should be noted in passing that Corney and Turkdogan[25] find an average equation from the results of Paranjpe *et al.* and the original results of Dijkstra, and point out the agreement between this and the equation representing the results of Fast and Verrijp. This is misleading as (*a*) the slope of the two lines whose average is taken differ by 18%, and (*b*) while accepting that Fast and Verrijp should apply a relationship N% = 1·26 × Q^{-1} max. to their internal friction results, they refrain from applying it to the internal friction results of Dijkstra. If they had they would have obtained results agreeing with the present ones. Similarly, Fast and Verrijp quote Dijkstra's value for the solubility at the eutectoid as being 0·08% N, whereas this is the internal friction and the corresponding nitrogen content is over 0·1%. Actually, using Dijkstra's figures the value for the internal friction corresponding to saturation at 590° C is 0·085, and the related nitrogen content is 0·107 agreeing with that found in this work.

The difference between the present results and those of Fast and Verrijp can be ascribed partly to the difference of 4% in the observed factors relating nitrogen content to Q^{-1} max. However, allowing for this, there still remains an unaccounted difference, which at 500° C amounts to 14% and at 300° C is about 30%. Fast and Verrijp state a possible error of ± 200 cal/g-mol Fe_4N for their heat of solution of Fe_4N in α-iron. An estimated error of ± 400 cal/g-mol Fe_4N would perhaps be more realistic.

Solubility of N_2

No direct measurement of the solubility of nitrogen under atmospheric pressure was made in the present work. However, it is useful to derive the solubility from the results for the $\alpha/\alpha + Fe_4N$ boundary and for the $\alpha/\alpha + \gamma$ boundary and to compare the figures derived with other direct determinations. In order to do so, use is made of the equilibrium constant for equation (2) estimated by Pearson and Ende,[14] and of various determinations[4, 25, 26] of the ammonia in the gas in equilibrium with α and Fe_4N, and with α and γ. Combining equation (1) and (2) we obtain,

$$\frac{[\text{N}]}{\sqrt{p_{\text{N}_2}}} = \frac{K_1}{K_2} = K_7 \ldots\ldots\ldots\ldots\ldots (7)$$

where K_1, K_2 ,and K_7 refer to equations (1), (2), and (7) respectively. The constant thus derived refers to the reaction

$$\tfrac{1}{2}\,\text{N}_2 = [\text{N}] \ldots\ldots\ldots\ldots\ldots (7a)$$

The calculated and observed results are plotted in Fig. 7. Several lines may be chosen as best representing the results, so reasons will be given for that actually drawn. One possible line is of greater slope, similar to one chosen by Corney and Turkdogan. This would assume large errors in the results of Fast and Verrijp for the solubility of N_2 in the lower temperature range, while accepting their results at 1450° C. It would assume either even larger errors in the solubility of Fe_4N in α-iron (this seems unlikely since the present results are in substantial agreement with other authors), or that the ammonia determinations by Lehrer, Emmett *et al.*, and Corney and Turkdogan are all much too low. This also seems unlikely. Another possibility is a compromise, namely, a curved relationship as drawn by Darken and Gurry.[26] This would place rather more reliance on the results of Corney and Turkdogan than on those of Fast and Verrijp, and also more reliance on those of Lehrer than on those of Emmett *et al.* This suggestion is rejected for the following reasons. The solubility determinations of Fast and Verrijp were made by use of internal friction results and, assuming their calibration is correct (and there is support for this assumption in this paper and in their own), their results are more likely to be accurate than those obtained by direct analysis. Lehrer's results when combined with this

paper's give solubilities at temperatures above the eutectoid which are discordant with those calculated for temperatures below the eutectoid.

For these reasons the line of best fit is believed to be represented by the equation

$$\log \frac{N}{\sqrt{p_{N_2}}}(N_2) = \frac{-1590}{T} = 1{\cdot}02 \quad \ldots\ldots(8)$$

Corney and Turkdogan give

$$\log \frac{N}{\sqrt{p_{N_2}}}(N_2) = \frac{-1980}{T} - 0{\cdot}795 \ldots\ldots(9)$$

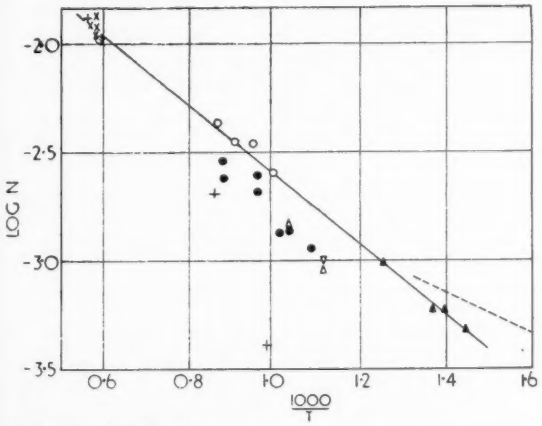
while Fast and Verrijp give

$$\log \frac{N}{\sqrt{p_{N_2}}}(N_2) = \frac{-1572}{T} - 1{\cdot}01 \ldots\ldots(10)$$

These equations correspond to a heat of solution of nitrogen of 7280, 9050, and 7200 cal/g-at. N.

The solubility line of N_2 at temperatures below the eutectoid, calculated from the $\alpha/\alpha + Fe_4N$ boundary due to Fast and Verrijp will be slightly lower than that calculated from the present results.

In the Appendix to their paper, Corney and Turkdogan reverse the method of calculation given here. Thus, using their equation for the solubility of nitrogen at 1 atm in α-iron, and an equation for the solubility of Fe_4N in α-iron, and various determinations of ammonia corresponding to saturated α-solutions, they calculate the free energy of formation of ammonia. They estimate the error of the resulting equation as being $\pm$ 500 cal. The corresponding equation due to Pearson and Ende is well outside these limits. If Corney and Turkdogan had used the equation for solubility of nitrogen given by Fast and Verrijp, they would have obtained an equation agreeing almost exactly with that estimated by Pearson and Ende.



(*A*) **Direct observations:**
+ Sieverts and Zapf[27] ○ Fast and Verrijp[24]
× Sieverts, Zapf, and Moritz[23] ● Corney and Turkdogan[25]

(*B*) **Calculated results**, all making use of Pearson and Ende's equation for the decomposition of ammonia[14]:
Δ Present results giving [N] for $\alpha/\alpha + \gamma$ phase combined with Lehrer's values for gas composition at the boundary[4]
— — — Present results giving [N] for $\alpha/\alpha + \gamma'$ phase combined with Lehrer's values for gas composition at the boundary[4]
▽ Present results giving [N] for $\alpha/\alpha + \gamma$ phase boundary combined with Corney and Turkdogan's value for gas composition at the boundary[25]
▲ Present results giving [N] for $\alpha/\alpha + \gamma$ phase combined with Emmett, Hendricks, and Brunauer's values for gas composition at the boundary[12]

Fig. 7—The nitrogen content of α-iron in equilibrium with nitrogen at one atmosphere

CONCLUSIONS

(1) The solubility of Fe_4N in alpha iron may be represented by the equation

$$\log N = \frac{-1649}{T} + 0{\cdot}942$$

(2) The $\alpha/\alpha + \gamma$ phase boundary for iron–nitrogen alloys has been determined and is given in Fig. 1

(3) From the present and from previous results an estimate of the solubility of nitrogen in α-iron has been given as a linear equation. However, the possibility is not overlooked that the temperature variation is not linear but may be curved as suggested by Darken and Gurry.[26]

APPENDIX

Calculation of the Internal Friction of a Quasi-isotropic Aggregate of B.C.C. Crystals

On theoretical grounds Polder[15] has deduced the strength of the anelastic effect for single crystals of interstitial solid solutions, namely:

$$\frac{\lambda 2}{\lambda 1} = \frac{2}{3}\frac{E}{RT} V C_o \frac{(e_{zz} - e_{xx})^2}{C_z}(1 - 3\Sigma a_1^2 a_2^2) \quad \ldots\ldots(11)$$

where $\lambda 1$ and $\lambda 2$ are the elastic and anelastic strains respectively, E is Young's Modulus of the iron crystal in the direction of strain, a_1, a_2, a_3 are the direction cosines between the direction of strain and the crystal axes, $3C_o$ is the ratio of the number of interstitial atoms to the number of iron atoms of the parent lattice, and e_{zz}, e_{xx} are the deformations along the z and x directions when there are c_z atoms of the solute on the z-places/atom of iron.

The calculated values of the anelastic effect due to carbon solution in the [100] direction of a cubic crystal of iron have been shown to agree with the experimental value.[15, 16] Using values of $\frac{e_{zz} - e_{xx}}{C_z}$ calculated from lattice constants of nitrogen martensite[17] the corresponding value for nitrogen may be calculated. Table IV shows that the agreement with the experimental results of Dijkstra on a single crystal is good.

To obtain similar results for an aggregate of crystals randomly oriented, rewrite equation (11)

$$\frac{\lambda 2}{\lambda 1} = S\,E(1 - 3\Sigma a_1^2 a_2^2) \quad \ldots\ldots(12)$$

where $S = \frac{2}{3}\frac{V}{RT}\frac{C_o\,(e_{zz} - e_{xx})^2}{C_z}$

Now[18] $E = \dfrac{1}{a - b\Sigma a_1^2 a_2^2}$ $\quad \ldots\ldots(13)$

where $a = \dfrac{1}{E_{100}}$ $\quad b = 3\left(\dfrac{1}{E_{100}} - \dfrac{1}{E_{111}}\right)$

so that

$$\frac{\lambda 2}{\lambda 1} = S\,\frac{3\Sigma a_1^2 a_2^2 - 1}{b\Sigma a_1^2 a_2^2 - a} = s\left(\frac{3}{b} - \frac{\dfrac{3a}{b} - 1}{b\Sigma a_1^2 a_2^2 - a}\right)$$

Transforming to polar co-ordinate ($a_1^2 + a_2^2 = \theta$ and $\frac{a_2}{a_1} = \tan\phi$), the average elastic strength $\bar{\lambda}$ of a group of randomly oriented crystals is

$$\bar{\lambda} = \frac{s}{\pi}\int_0^{\frac{\pi}{2}}\int_0^1 \left(\frac{3}{b} + \frac{3a - 1}{b}\right)\frac{d\phi d\theta}{\sqrt{1-\theta}} \quad \ldots(14)$$

where $f(\theta,\phi) = \theta\{1 - \theta(1 - \cos^2\phi\,\sin^2\phi)\}$

The integral $\dfrac{1}{\pi}\displaystyle\int_0^{\frac{\pi}{2}}\int_0^1 \frac{d\phi d\theta}{\{a - bf(\theta,\phi)\sqrt{1-\theta}}$

Table IV

CALCULATED AND OBSERVED VALUES OF $n_{[100]}$ FOR 0·01% OF SOLUTE IN A SINGLE CRYSTAL OF IRON AT 17° C

	Carbon in iron	Nitrogen in iron
Calculated value	0·0407	0·0332
Observed value (Dijkstra)	0·043[16]	0·032[16]

has been used to calculate Young's Modulus for a group of randomly oriented crystals,[19] the calculated value being within 10% of the observed value for iron.[20] Thus,

$$\bar{\lambda} = \frac{s}{\pi}\left\{\int_0^{\frac{\pi}{2}}\int_0^1 \frac{3d\phi d\theta}{b\sqrt{1-\theta}} + \left(\frac{3a}{b}-1\right)\left(-\bar{E}\pi\right)\right\}$$

Putting[20] $a = 0{\cdot}074 \times 10^{-8}$ (g/cm²)$^{-1}$

$b = 0{\cdot}1185 \times 10^{-8}$ (g/cm²)$^{-1}$

and $\bar{E} = 21 \times 10^6$ g/cm²

then $\bar{\lambda} = 7s \times 10^8$

$$\text{Thus } \frac{\bar{\lambda}}{\lambda_{100}} = \frac{7 \times 10^8 \times s}{E_{100} \times s} = \frac{7}{13{\cdot}5} = 0{\cdot}518$$

The calculated and observed values of $\bar{\lambda}$ are given in Table V. The agreement is seen to be fairly satisfactory. The disagreement may be due to errors in the various values of constants used. A small error in the values used for the various constants is magnified in the final result which depends upon the difference between two comparatively large terms. It may be however that an aggregate of crystals do not behave independently (implicit in the mathematical analysis) and that there is some interaction at crystal boundaries. If so, it would appear that the interaction is small.

Since making the above calculation the authors have become aware of the work of Smit and Van Beuren[29] who, using a semi-empirical method, deduced the following values for the height of the internal friction peak due to nitrogen in solution in iron:

for bending: Q^{-1} max. $= \dfrac{1{\cdot}9 \times 10^2\ \text{N}}{T}$

and for torsion: Q^{-1} max. $= \dfrac{2{\cdot}2 \times 10^2\ \text{N}}{T}$

When put in this form, the values from the present work become

Table V

CALCULATED AND OBSERVED VALUES OF $\bar{\lambda}$ FOR 0·01% OF SOLUTE IN A RANDOMLY ORIENTED AGGREGATE OF IRON CRYSTALS AT 17° C

	Carbon in iron	Nitrogen in iron
Directly calculated value	0·0211	0·0172
Calculated value based on observed value for single crystal	0·0223	0·0166
Observed value	about 0·02	0·0159 ± 0·004

for bending or torsion (calculated):

$$Q^{-1}\text{ max.} = \frac{2{\cdot}39 \times 10^2\ \text{N}}{T}$$

and for torsion (observed): Q^{-1}max. $= \dfrac{2{\cdot}26 \times 10^2\ \text{N}}{T}$

The corresponding value observed by Fast and Verrijp is (for torsion)

$$Q^{-1}\text{ max.} = \frac{2{\cdot}34 \times 10^2\ \text{N}}{T}$$

The agreement for the case of torsion is thus very satisfactory.

Possible reasons for the inaccuracy of the present calculation have already been given. The calculation of Smit and van Beuren being of a semi-empirical nature is believed to be the more accurate.

Acknowledgment

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Increased Heating Rates for Steel Ingots

By P. M. Cook, B.Sc., A.Inst.P., A.I.M., and J. D. Stringer, B.Sc.

SYNOPSIS

Experiments are described which suggest that conventional heating times for both low and highly allowed steel ingots prior to hot working are unnecessarily long. Both in the laboratory and in works' trials, small high-speed steel ingots have been heated for forging satisfactorily in 1 h. The quality of finished products after rapid heating have so far met commercial requirements. As a result of this work, several firms have reduced their heating times by various means with beneficial results.

The potential advantages of rapid heating are increased production from existing furnace capacity, reduction of scale losses and decarburization, and fuel economy. 1351

Introduction

THE HEATING of ingots and billets for hot working is a time-consuming and relatively costly operation which, if done more slowly than is absolutely necessary, can lead to waste of fuel, time, and steel (by scale formation). In view of the current high cost of fuel, shortage of steel, and need for maximum plant utilization, it is now more important than ever before to reduce heating times to a minimum.

Notable advances have been made in recent years in the development of low-frequency induction heating methods and of concentrated combustion-type gas burners which have made the heating of billets of up to about 6-in. section possible at rates as high as 1 min per inch of section. Induction methods and their application to high-production heating are described for example by Logan,[1] Hobbs,[2] and Baffrey.[3] Rapid gas heating of billets has been enthusiastically developed and applied by the Selas Corporation and others in the U.S.A.[4, 5, 6]

It is clear from these various reports that rapid heating by induction or gas is now well established for low-alloy steels in billet form, but the heating of ingots of large section and/or high in alloy content still remains a slow process which has not perhaps received as much attention as it deserves. The main factor governing the rate at which ingots may be heated is the susceptibility of the material to 'clinking', a term used to describe the occurrence of transverse fractures caused by thermal (expansion) stresses set up by the temperature gradient from surface to core. An as-cast ingot structure, because of its lower ductility, is more susceptible to clinking than one broken down by previous hot working, e.g. billet stock, and the susceptibility also increases with carbon and alloy content for the same reason.

Heating rates for ingots vary, quite naturally, from plant to plant, but on the average are in general agreement with those advocated by Trinks,[7] namely, 20 min per inch of diameter for low-carbon steel and 30–35 min per inch for high-carbon and alloy steel. Much slower rates are often used for the heating of very highly alloyed ingots of, for example, high-speed tool steels. Two recent papers dealing with the rapid heating of ingots are therefore of particular interest. Terlecki[8] reports drastic reductions in heating times for all types of steel and claims increased production, improved quality of final product, and considerable fuel economy. Terlecki's method for low-alloy steels and plain carbon steels up to 0·85% carbon is to charge the cold ingot into a furnace held above the eventual working temperature (at say 1400° C) and to withdraw immediately the surface

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Table I

DETAILS OF TESTS

Test	Ingot	Furnace Temp., °C	Withdrawn After	Purpose of Test	See Fig.
1	8 in., En 26	1380	41 min	Temperature records	1
2	8 in., 0·6% C	1350	33 min		2
3	10 in., 0·6% C	1350	62 min		3
4	8 in., 0·6% C	Heated slowly to 1200° C in 6 h and soaked for 1½ h		To compare temperature distributions during air cooling with those from Tests 2 and 3	4
5	10 in., 0·6% C				5
6	8 in., En 26	As for Test 1		Quality of forged 4 in. billet	
7	8 in., En 26			Quality of forged 5 in. billet	
8	10 in., 0·6% C	As for Test 3		Comparison of forging loads	6
9	10 in., 0·6% C	As for Test 5			

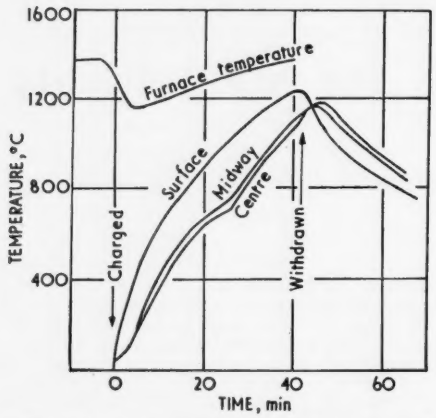


Fig. 1—Record of temperatures in 8-in. square En 26 (2½ Ni–Cr–Mo) ingot

reaches a specified safe limit (say 1300° C). For the more brittle highly alloyed steels, pre-heating by charging at 600–800° C precedes transfer to another furnace held again at a temperature in excess of that required for hot working. Prolonged soaking of ingots at forging or rolling temperature is considered quite unnecessary. An example of this method, quoted by Terlecki, is the heating of a 0·25% carbon steel ingot, weighing 8 tons and being 35 in. in diameter, to 1300°C in a little over 3¼ h. It is claimed that this rapid heating principle is being applied successfully and with great advantage in several Polish steelworks. Hess,[9] dealing with the applications of the Selas concentrated combustion burner, describes heating of 19 in. × 23 in. × 78 in. mild-steel ingots from cold in 2 h, followed by satisfactory rolling.

In view of the undoubted industrial importance of these reports, the authors undertook experiments to ascertain how quickly ingots of various sizes and qualities could be raised to hot-working temperatures without structural damage. Laboratory equipment imposed an upper limit of 10 in. square on the ingot section size; nevertheless, much valuable information was gained, particularly with respect to the rapid heating of high-speed steel. This paper describes the experimental work and gives details of various works trials and applications of rapid heating methods. The

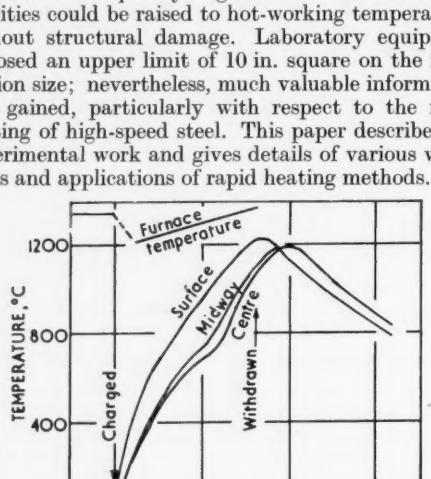


Fig. 2—Record of temperatures in 8-in. square 0·6% C steel ingot

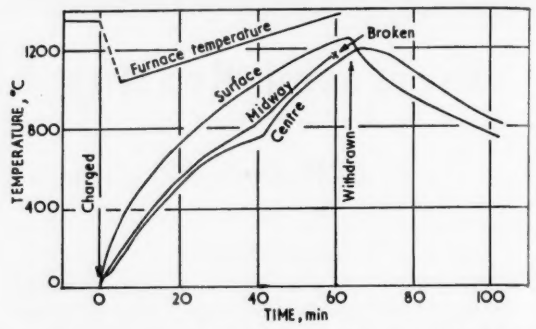


Fig. 3—Record of temperatures in 10-in. square 0·6% C steel ingot

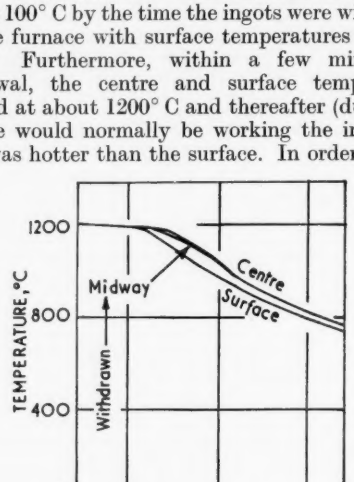
quality of finished products from ingots heated more rapidly than usual have also been studied.

HEATING EXPERIMENTS

Plain Carbon and Low-alloy Steels

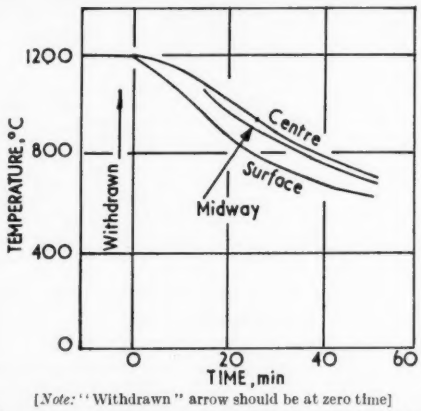
Eight inch square ingots of En 26 type steel (2½% Ni–Cr–Mo) and 8-in. and 10-in. plain 0·6% carbon steel, were individually charged cold and in the as-cast condition into a gas-fired furnace standing at temperatures in the range 1350–1400° C, as advocated by Terlecki. Some of the ingots were drilled to take thermocouples for temperature recording at the centre, midway, and within ⅛ in. of the surface. In all other cases surface temperatures were obtained from peened-in thermocouples. None of the ingots clinked and information was obtained on heating and cooling rates, temperature gradients, forgeability, and soundness. Details of the tests are given in Table I.

Reference to Figs. 1, 2, and 3 shows that, during rapid heating, temperature differences of the order of 300° C between surface and centre occurred during the α–γ transformation. These differences decreased to about 100° C by the time the ingots were withdrawn from the furnace with surface temperatures of about 1250° C. Furthermore, within a few minutes of withdrawal, the centre and surface temperatures equalized at about 1200° C and thereafter (during the time one would normally be working the ingot) the centre was hotter than the surface. In order to com-



[*Note:* "Withdrawn" arrow should be at zero time]

Fig. 4—Air-cooling curves for 8-in. 0·6% C steel ingots after slow heating and soaking for 1½ h



[*Note:* "Withdrawn" arrow should be at zero time]

Fig. 5—Air-cooling curves for 10-in. 0·6% C steel ingots after slow heating and soaking for 1½ h

pare these temperature distributions in the hot-working range with those occurring in conventionally heated and well-soaked ingots, Figs. 4 and 5 should be examined. It is seen that conditions are very similar and, unless required for metallurgical reasons, it would seem that the soaking of ingots of this size is unnecessary even after very rapid heating.

In order to determine the effect of rapid heating on quality and forgeability, two 8-in. ingots of En 26 were heated in approximately 40 min (Tests 6 and 7) and forged down to 4-in. and 5-in. square billets. These billets were examined ultrasonically, sectioned, and macro-etched. No flaws of any kind were found. Press-load versus stroke records were also obtained during similar forging strokes on two 10-in. 0·6% C steel ingots, one heated rapidly, the other heated slowly and soaked (tests 8 and 9). The records (Fig. 6) reveal no significant differences between the powers required to deform the two ingots.

The above tests confirm that very rapid heating is possible for low-alloy and medium-carbon steel ingots of up to say 10-in. section without detriment to the final forged product.

High-speed Tool Steel

In view of the fact that a 10-in. square ingot was the largest that could be handled in the laboratory, subsequent work was concerned with the possibility

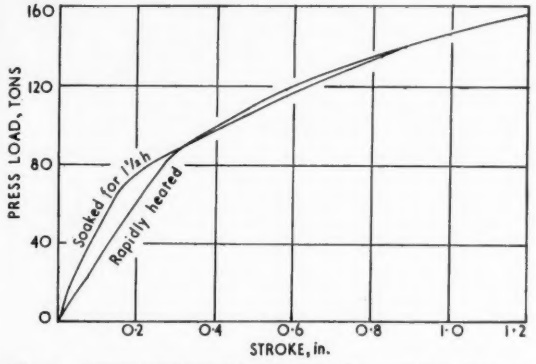


Fig. 6—Press-load/stroke records for rapidly heated and soaked 10-in. 0·6% C steel ingots

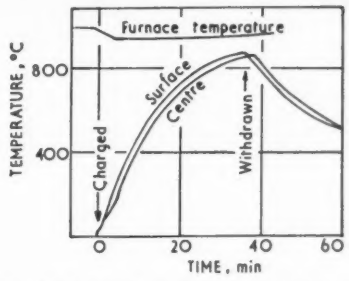


Fig. 7—4-in. high-speed steel ingot charged at 1000° C

of rapid heating as applied to highly alloyed steel. A composition of 18% W, 4% Cr, 1% V, was chosen as a typical example of a steel produced commercially in appreciable quantity and in sizes which could be conveniently dealt with in the laboratory. It is also a quality which is normally treated very carefully during heating—charging at no more than 500–600° C, slow heating for up to 12 h, and long soaking being quite customary for ingots of 6 in. square section. Since surface decarburization and excessive scaling due to prolonged heating are both undesirable, this class of material was considered ideal for possible applications of more rapid heating methods.

Tests were carried out on both 4-in. and 6-in. square ingots of 110 lb and 220 lb respectively. They were made in acid-lined high-frequency furnaces, stripped from the ingot moulds at 800–850° C, and cooled on racks. All were supplied to an analysis specification of 0·70–0·75% C, 0·2–0·4% Si, 0·1–0·4% Mn, 3·9–4·4% Cr, 17·5–19·0% W, 0·9–1·5% V, $< 0·3\%$ Ni, $< 0·5\%$ Co.

It was anticipated that this type of material, even in the 4-in. square size, would not stand charging at the high temperatures found possible for low-alloy steel. The aim of the experiments was therefore to determine the maximum safe charging temperatures for the cold as-cast ingots, and subsequently to find out at what temperature they could be safely transferred to a high-temperature furnace for rapid heating to working temperature.

The results of the preheating tests for both 4-in. and 6-in. ingots are given in Table II.

These tests suggested that 1000° C and 900° C were safe temperatures at which to charge cold as-cast 4-in. and 6-in. ingots respectively for preheating. The surface and centre temperatures during heating under these conditions are shown in Figs. 7 and 8.

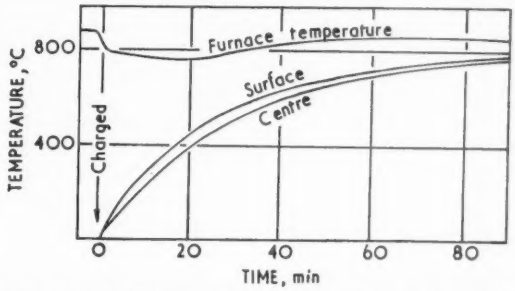


Fig. 8—6-in. high-speed steel ingot charged at 900° C

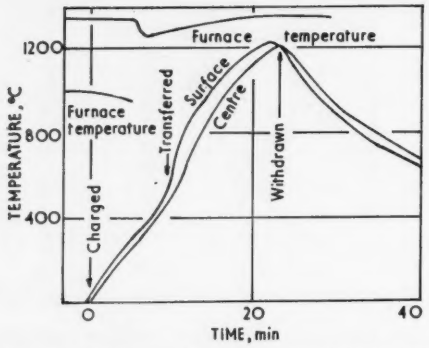


Fig. 9—4-in. high-speed ingot charged at 1000° C, transferred to 1350° C

Annealed ingots will apparently withstand a temperature about 100° C higher.

The next stage was to determine to what temperature the ingots needed preheating in order to have sufficient ductility to withstand transfer to a second furnace maintained at 1350° C. It was quickly established that 4-in. ingots, charged cold into the preheater at 1000° C, could be transferred to a furnace at 1350° C quite safely after only 5 min, i.e. at an ingot temperature of approximately 300° C (*see* Fig. 7). The full temperature/time record to an ingot temperature of 1200° C in 22 min under these extreme conditions is shown in Fig. 9.*

The results of similar tests with 6-in. ingots are given in Table III.

These tests showed that 6-in. ingots, charged cold into a preheater at 900° C, could be safely transferred to the 1350° C furnace after 30 min at an ingot temperature of about 500° C. The temperature/time record to an ingot temperature of 1170° C in 53 min is shown in Fig. 10; the high-temperature furnace was held at 1300° C in this instance.

Practical Heating Cycles

The foregoing experiments were valuable in that they established that high-speed steel could be heated much more rapidly than was currently practised without structural damage. The use of a furnace at 1350° C, however, requires very careful timing and constant vigilance if overheating is to be avoided and is only feasible under carefully controlled conditions. With a view to trying rapid heating in the works, therefore, a more practical heating cycle, allowing more latitude in timing, was established. It involved charging the ingot (either 4-in. or 6-in.) into a preheater at 800° C and transferring after 30 min to a furnace at 1200–1230° C for a further period of not less than 30 min. No risk of overheating is entailed, should the ingot be left in the second furnace for more than 30 min. Temperature records for both ingot sizes under these conditions are shown in Figs. 11 and 12.

Effect of Rapid Heating on Forgeability and Structure

Press-load versus stroke records were taken during forging of both 4-in. and 6-in. ingots after heating in accordance with the 1-h cycle and also after slow heating over a 24-h period. As with the low-alloy steels, no significant differences were observed.

The microstructures of 2 in. square billets and $\frac{5}{8}$ in. square bars forged from the 4-in. ingots were also examined. It is normal practice with high-speed steels to reduce the ingot section by about 75% (to 2 in. square in this case) after the first heating, and subsequently to reheat from cold for further reduction to finished size. This second heating is usually quite rapid and in the current experiments was done conventionally in about 1 h. The microstructures are shown in Fig. 13. Although the structure has been broken up to some extent at the 2-in. billet stage in the rapidly heated material, the characteristics of the as-cast structure and the carbide network persist to a greater degree than in the slowly heated material. After the second heat and further reduction to $\frac{5}{8}$-in. bar, however, the structures are almost identical. An experienced eye might consider the carbide pattern to be slightly better after slow heating, but the difference is no more than would be expected between different ingots. Surface decarburization was markedly less in the rapidly heated bars.

Table II
RESULTS OF PREHEATING TESTS

Ingot Size	Number of Ingots Charged	Condition before Heating	Furnace Temp., °C	Condition after Heating
4 in.	1	Annealed	1300	Clinked
	1	Annealed	1200	Sound
	1	As-cast	1200	Clinked
	1	Annealed	1100	Sound
	1	As-cast	1100	Sound
	5	As-cast	1000	All sound
6 in.	1	Annealed	1300	Clinked
	2	Annealed	1200	1 Sound, 1 Clinked
	5	Annealed	1100	All sound
	1	As-cast	1100	Clinked
	5	As-cast	1000	All sound
	9	As-cast	900	All sound

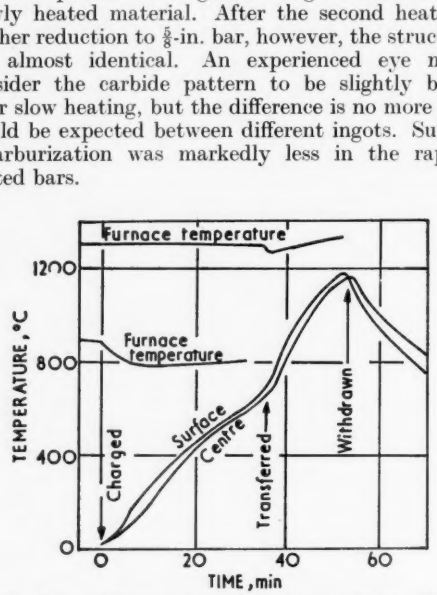


Fig. 10—6 in. high-speed steel ingot charged at 900° C, transferred to 1300° C

* The actual time to transfer was a little over 5 min in this case, owing to handling difficulties with an ingot carrying thermocouples and trailing leads.

Table III
AS-CAST 6-IN. HIGH-SPEED STEEL INGOTS CHARGED COLD INTO 900° C FURNACE

Number of Ingots	Time in 900° C Furnace, min	Approximate Temperature when Transferred, °C (from Fig. 8)	Condition in 1350° C Furnace
1	10	250	Clinked
2	15	350	1 Clinked, 1 Sound
6	30	500	All sound

WORKS' TRIALS

The results obtained in the laboratory clearly warranted rapid heating trials with high-speed steel ingots under works' conditions. Such trials were necessary, particularly since all the laboratory forging was done under a 200-ton hydraulic press, whereas most high-speed steel forging is done under power hammers.

The first two trials were therefore organized to assess the forgeability of rapidly heated high-speed steel ingots under hammers. In one works, six annealed 4-in. ingots (18/4/1 type) were heated in accordance with the 1-h cycle previously described; the preheating furnace was coal-fired, the high-temperature furnace was gas-fired. In order to give each ingot the correct 1-h cycle and at the same time to ensure continuous forging, they were charged into the preheater and later transferred to the high-temperature furnace at 15-min intervals. Once the cycle of operations was established (after 1 h) ingots were ready for forging at intervals of 15 min. None of the ingots clinked, and all were forged to 2 in. square billet under a 1-ton steam hammer. The hammer man detected no difference in forgeability compared with conventionally heated ingots. In another works, twelve as-cast 4-in. ingots were heated using the 1-h cycle and two coal-fired furnaces. Again none of the ingots clinked and the firm's technical staff formed the impression that the ingots forged very well. On knocking off the cold bar ends, they were very satisfied with the appearance of the fractures.

Quality of Finished Product

Having ascertained that rapidly heated ingots could be satisfactorily forged, it was next necessary to examine the properties and quality of the finished product before advocating more widespread adoption

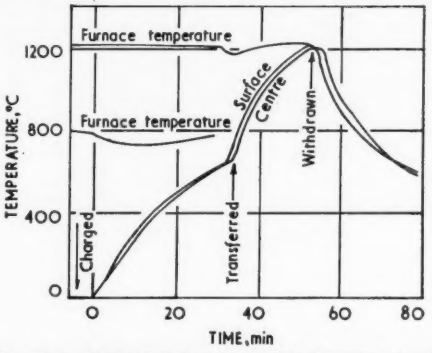


Fig. 11—4-in. high-speed steel ingot charged at 800° C, transferred to 1230° C

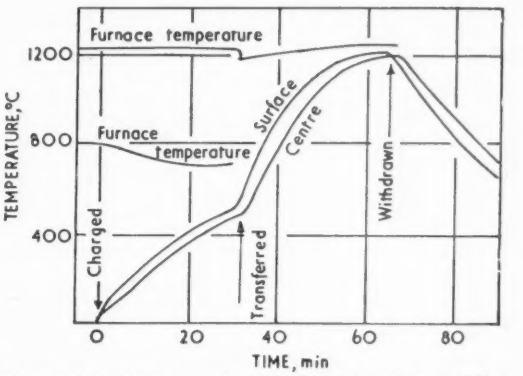


Fig. 12—6-in. high-speed steel ingot charged at 800° C, transferred to 1230° C

of the technique. A third works' trial was therefore organized, in which six ingots from a cast of 4-in. square 18/4/1 type high-speed steel were heated rapidly, and six were raised slowly to 1150–1200° C and soaked over an 18-h period. After hammer cogging to 2 in. square, the bars were reheated and reduced to $\frac{1}{2}$ in. and $\frac{5}{8}$ in. square sections. The microstructures were similar to those illustrated in Fig. 13. The bulk of the material was made into standard $\frac{1}{2}$ in. and $\frac{5}{8}$ in. square tool bits. Blanks were air-hardened from 1290–1300° C and double tempered at 540–550° C. After grinding to size, all were tested for hardness and inspected with the following results:

Tool bits from rapidly heated ingots:

$\frac{1}{2}$ in. square—198 made, 1 rejected
$\frac{5}{8}$ in. square—119 made, 4 rejected

Tool bits from conventionally heated ingots:

$\frac{1}{2}$ in. square—204 made, 4 rejected
$\frac{5}{8}$ in. square—88 made, 25 rejected.

All the tools passed the Rockwell hardness test of 63 C minimum, the rejections being due to surface cracks or the impossibility of cleaning up by grinding at the required size. Since the latter fault is purely one of dimensional accuracy when finishing forging, it would be unwise to conclude that the rapidly heated material gave a better product. It is apparent, however, as far as production and commercial quality are concerned, that the rapidly heated material proved at least as satisfactory as that which was heated conventionally. No opportunity was afforded for performance testing of any of these tools; they were all absorbed into normal production and distributed with no subsequent repercussions.

A small quantity of the bar produced in this trial was however put aside and made into $\frac{7}{16}$ in. diameter twist drills, all of which passed the B.S.S. drill test and were then tested to destruction. Appreciable scatter was evident in the numbers of holes drilled, and no significant difference was established between the performances of the rapidly and slowly heated materials. The value of these tests was limited, as only eight drills of each kind were made. Another more detailed and comprehensive quantitative test of quality is now being organized.

INDUSTRIAL APPLICATION

During the various works' trials reported above,

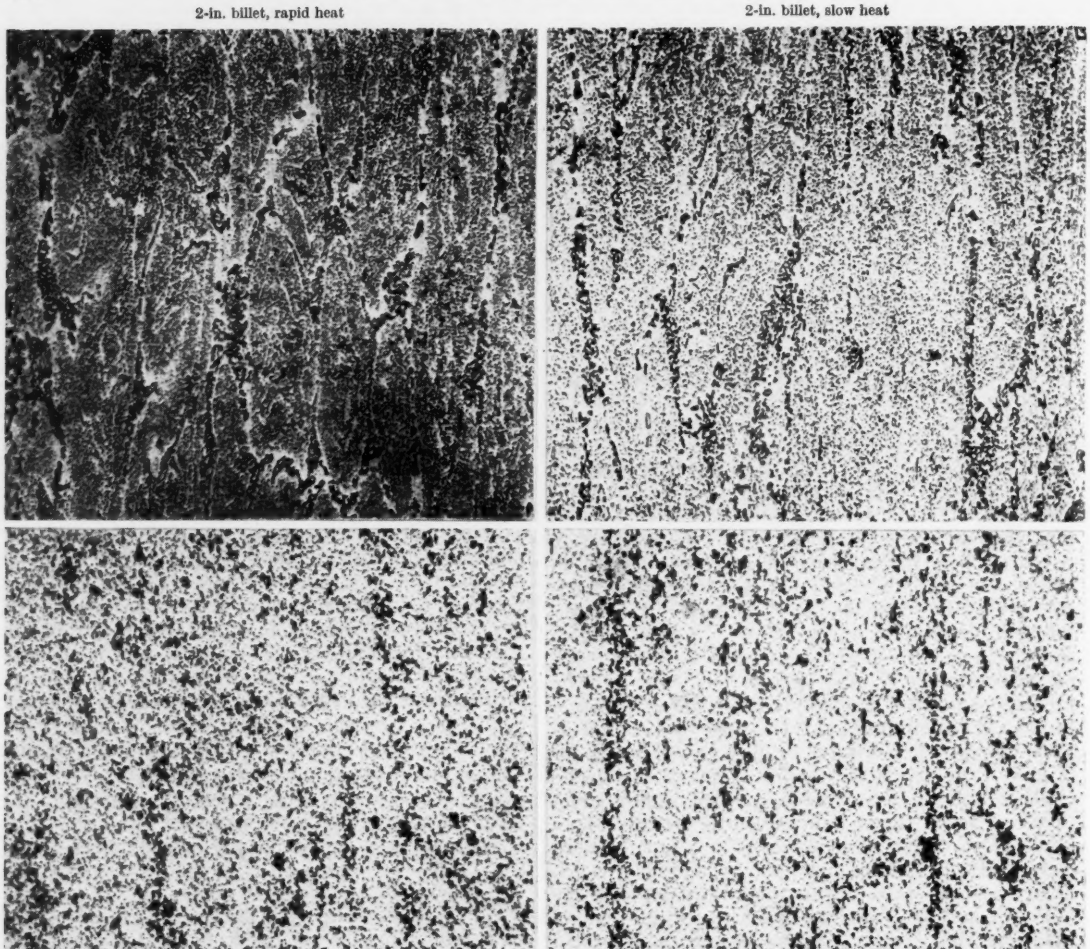


Fig. 13—Microstructures of forged high-speed steel: etchant—alkaline $KMnO_4$ × 250

our attention was drawn to the fact that the two-stage method of heating might be difficult to apply on a continuous production basis due to unsuitable furnaces, layout, handling facilities, etc. This observation is of course appreciated; the two-stage method of heating was devised for the purpose of achieving the most rapid heating rates possible in the laboratory, and it is accepted that in any application of rapid heating in a particular works, the actual procedure chosen will be governed by the plant available. Many companies have in fact already reduced their heating times with considerable benefits, although in most cases, because of the preference for charging in batches rather than singly, the heating is not as rapid as the laboratory tests have shown to be possible.

At one particular works, as-cast high-speed steel ingots of 4 in. and 6 in. square section are now charged in batches into furnaces at about 600° C and raised to 1150–1200° C in 6 h. Forging then proceeds at once. This compares with the previous practice of raising to 1150–1200° C in about 8 h, followed by a 7-h soak at this temperature. This modification to the heating process, i.e. soaking eliminated, whilst only a minor one by the laboratory standard, has resulted in a reduction of troublesome surface decarburization (particularly on 6/5/2 molybdenum-type steel) to an insignificant level. Scale losses and coal consumption have also both been reduced, although no quantitative assessment of the saving is available.

In another works an interesting and effective modification has been made to a modern continuous gas-fired pusher-type furnace. This furnace supplies a 50-cwt hammer with a wide range of ingots including 18/4/1 type high-speed steel, cobalt-bearing high-speed steel, 6/5/2 molybdenum-type high-speed steel, 22% W 10% Co, 2% C 13% Cr, and 0·4% C 8% W, all in various sizes up to 12 in. square.

In its original state the furnace operated with four burners in the end wall and occasionally two

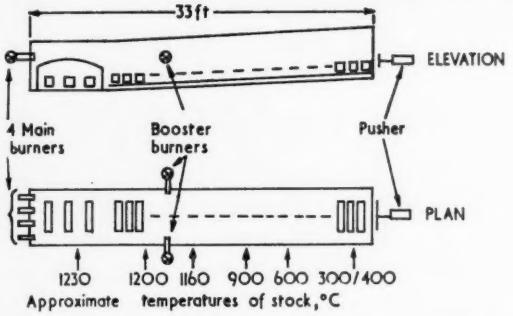


Fig. 14—Schematic arrangement of continuous furnace before modification

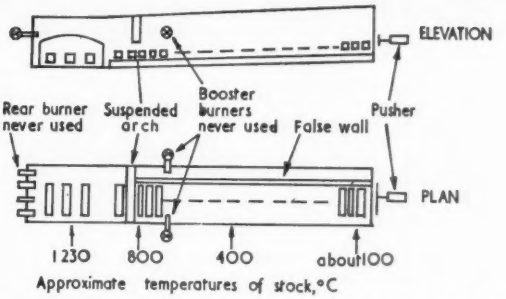


Fig. 15—Schematic arrangement of continuous furnace after modification

booster burners as shown diagrammatically in Fig. 14. This figure also shows the approximate temperatures of the stock at various positions in the furnace during a typical normal production run. With an average travelling time of about 8 h, it is seen that the ingots were at 900° C and over for about 5 h. The furnace has now been modified by building a suspended arch 10 ft from the end wall with just sufficient clearance to allow the largest ingots to pass underneath, as shown in Fig. 15. At the same time a false wall has been erected to eliminate unnecessary width 'upstream' of the arch. The full width is required in the high-temperature zone only for finishing work. The effect of this modification has been to restrict the flow of hot gases up the furnace, thus causing a pronounced temperature difference on either side of the arch. The ingot temperatures along the furnace during normal working are again shown in Fig. 15, from which it is evident that the material is kept below scaling temperatures until it reaches the arch. A rapid heating to forging temperature then occurs, the ingots being no more than $1\frac{1}{2}$ h at temperatures above 800° C. As a result of this modification the furnace now operates with only three burners in the end wall and without the booster burners. There is obviously an appreciable fuel saving but no definite figures are available. Scale losses are also reduced; the amount of scale now collected for tungsten recovery being about half that previously handled. Complaints from customers about decarburization have now come to an end.

It is worth emphasizing that all the above-mentioned 'difficult' steels are being heated in sizes up to 12 in. square in the manner described. The hammer crew have noticed no differences whatsoever in the forgeability of any quality and to date many hundreds of tons of ingots (all unannealed) have been forged with complete satisfaction.

CONCLUSIONS

The forging experiments and works' trials have shown that in certain specific cases ingot heating times are unnecessarily prolonged. Terlecki's principle of charging low-alloy steel ingots into furnaces held above the desired final temperature has been applied successfully to medium-carbon and En 26 type ingots of up to 10 in. square section. Owing to the limitations imposed by laboratory equipment, Terlecki's claim that much larger ingots may be heated rapidly in this manner could not be tested. Co-operative industrial trials with large ingots would be well worthwhile.

It has been shown, both in the laboratory and in works' trials and applications, that small ingots of highly alloyed tool steels may be heated much more rapidly than is currently practised without detriment to the quality of the finished products. The practical heating cycles developed by the authors completely eliminate the dangers of overheating the steel which are inherent in the original cycles proposed by Terlecki.

Several companies have adopted this approach by cutting down their heating and/or soaking times with noticeable advantages in respect of fuel consumption, scale formation, and decarburization. Other firms, about to install new rolling and forging plant are considering the adoption of the continuous furnace design which incorporates a suspended arch to restrict the size of the high-temperature zone. It is clear that reheating times could be cut down even further if high-intensity burners were used in specially designed furnaces.

Acknowledgments

The authors wish to express their appreciation, for invaluable discussions and material help, to the many members of the staffs of Arthur Balfour and Co., Ltd., Thos. Firth and John Brown Ltd., English Steel Corporation Ltd., Meadows and Co., Ltd., George Senior and Sons Ltd., Jonas and Colver Ltd., Sanderson Bros. and Newbould Ltd., William Jessop and Co., Ltd., Henry Eadon and Sons, and others who have been so keenly interested in the progress of this work.

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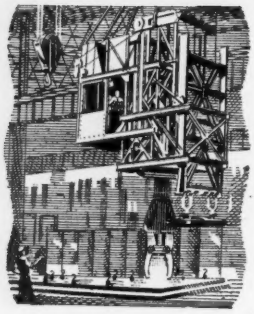

IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group

Positive-type Rotary Compressors

By V. Barnett, A.M.I.Mech.E.

SYNOPSIS

The modern positive-type rotary compressor is extremely reliable and has many advantages. Details are given of machines representative of present day practice and the technical data include efficiencies and limitations of pressure and outputs.

A comparison is made between single- and two-stage compressors at 60 lb/in² and the economy achieved by boosting is illustrated.

Methods of controlling output and various types of shaft glands are described. Finally, the paper includes general information concerning maintenance, cooling systems, and oil separation. 1353

WHEN IT IS CONSIDERED that a machine running continuously for a year at 500 rev/min revolves 262 million times, it is easy to see why, in the engineering world, it is generally acknowledged that if a rotary device can be provided for a given purpose, then it is an improvement on a reciprocating mechanism. In many fields the trend of engineering progress is towards the development of rotary machines, and this is the driving force which has caused the evolution of the positive-type rotary compressor.

Nevertheless the development has not been easy, and only during the last 20 years has the two-stage rotary compressor reached its present high standard of reliability and efficiency. As far back as the middle of the nineteenth century, designs were being produced and machines built but all seem to have suffered from excessive blade or other types of wear and to have been inefficient owing to excessive friction and air slip. The first real advance in the design of positive-type rotary compressors took place about 1910 when continental designers patented what was termed the 'restraining ring,' and the next major development occurred in 1919 when British designers invented the 'rolling drum.' Both these ideas are still used and are the basis from which two of the designs were developed which will be discussed in the paper.

Many advantages can be claimed for the positive-type rotary compressor, and the following are common to the four different designs which will be considered, and which are representative of present-day practice.

(i) There are no suction or delivery valves, other than a non-return valve which is held open by the continuous flow of air, and shuts when the machine stops or is running light, thus preventing motoring of the compressor and loss of air from the mains
(ii) Rotary motion eliminates fatigue in working parts caused by alternating stresses
(iii) There is no reversed flow of air and no suction stroke during which hot compressed air can be re-admitted to the cylinder through defective discharge valves, this being the major cause of explosions in air compressors
(iv) The rotary machine is free from vibration and there are no air pulsations from the suction which can cause objectionable rattling of windows and buildings
(v) Minimum foundations only are required. The machines are ideal for installation on 'made' ground, and it is only necessary to provide a light plinth which will not distort when supporting the weight of the complete unit. A rotary compressor can be run without bolting down, but it is usual to fasten down the bedplate, as this provides the true surface on which the machine is aligned and dowelled.
(vi) Direct coupling to high-speed driving units is possible. This permits the use of reasonably priced motors and avoids the necessity for **V**-belt drives with their power loss and belt renewals.
(vii) Rotary compressors maintain their initial efficiency for long periods and there is no deterioration in output due to valve leakage
(viii) Maintenance costs are low.

The four individual designs which will be considered in the paper each have their own additional advantages and these will be referred to in the following detailed descriptions.

Rolling-drum Compressor

This was one of the earliest of the successful rotary compressors, but it has certain features which limit its application to relatively low-pressure work. It may,

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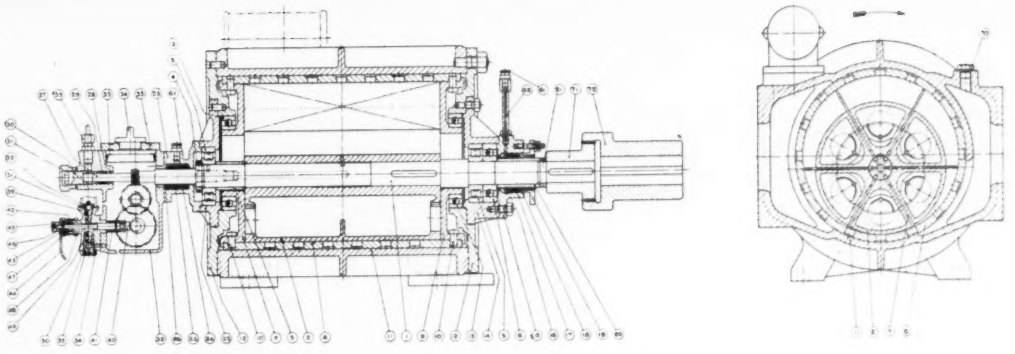


Fig. 1—Sectional arrangement of air-cooled rolling-drum compressor

however, be used for both air and gas. Figure 1 shows a sectional arrangement of an air-cooled rolling-drum compressor in which the blades are prevented from rubbing on the cylinder by an accurately machined and perforated drum which is free to rotate on ball-bearings mounted in the end covers, the running clearance between drum and cylinder being small. The rotor, slotted for eight blades, is mounted on its own bearings and is located axially by a thrust bearing. The glands are of the soft packing type, and internal lubrication is supplied by a mechanical lubricator.

Figure 2 shows a compressor partly assembled and illustrates the blades, which fly out by centrifugal force on to the rolling drum, itself carried round by the blades. The tip-speed of the blades at the top of the cylinder is greater than at the bottom, whereas the drum has to take up an average speed and as there is a small amount of relative movement between blades and drum, the rate of wear is small. Because of the complete support of the blades, rotating speeds can be high, the machine is balanced, and frictional losses are low.

Air is continuously drawn in through the suction branch and port, then through the perforations in the rolling drum which, to avoid interrupting the air flow, are drilled in rows at an angle to the axis. The air is then compressed by the reduction of the spaces enclosed by the rolling drum, rotor, and the several blades, and as the latter pass the delivery port the air is discharged through the perforations of the drum.

The features which limit the working pressure of this design would appear to be the difficulty of getting the heat away because of the rolling drum, which to some extent acts as an insulator. There is also leakage loss from cell to cell through the drum perforations and around the clearance between drum and cylinder.

Figure 3 shows the range of air-cooled machines available and the b.h.p./output curves at pressures of 5, 10, and 15 lb/in². Water-cooled machines of modified design are also available for pressures up to 30 lb/in².

Screw Compressor

This type was originally conceived for use as a surge-free component of a gas turbine but it soon became evident that the machine could be adapted for industrial purposes, and subsequent major development work has been directed towards providing a stable and compact rotary compressor.

Figures 4 and 5 show the general view and the sectional arrangement of a single-stage compressor which has two intermeshing rotors cut in the form of a screw thread and synchronized together by timing

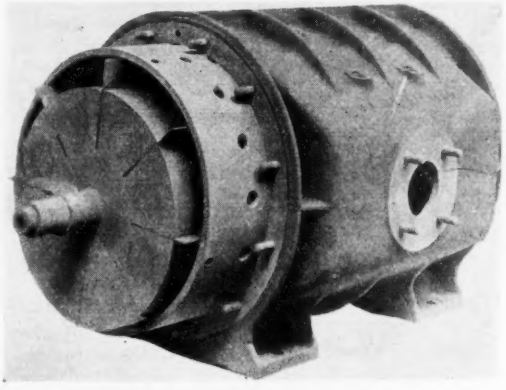


Fig. 2—Partially-erected rolling-drum compressor

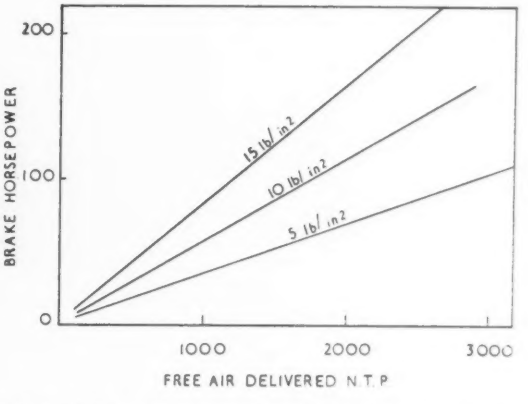


Fig. 3—Performance curves for air-cooled rolling-drum compressor

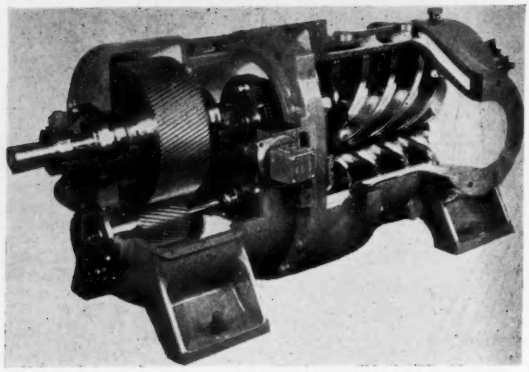


Fig. 4—Cutaway view of single-stage screw-type compressor

gears which are capable of transmitting up to 10% of the total power. The air cushion between the lobes transmits the necessary power from the four-lobe driving rotor to the six-lobe follower, and in practice it has been found that the timing gears themselves have to transmit less than 5% of the total power.

The rotors have to carry considerable bending forces owing to pressure difference, so that to get the required stiffness it has been found necessary to use additional lobes in the follower which has the effect of increasing the diameter of the boss at the root of the lobes. With the four plus six lobe construction now used, the bending stresses in each rotor are about equal.

Although the clearance between rotors is small, the lobes do not touch, and the necessarily fine radial clearances are achieved by the use of sealing strips formed on top of the rotor lobes during the milling process. With this construction, exceedingly fine clearances are practicable without danger of seizure, and if necessary the strips (or fins) are rubbed down during the initial run without damage to the machine.

The screw-type compressor is suitable for coupling to high-speed driving units, and incorporates its own built-in increasing gears to step up the speed to the required rotor revolutions. Flexibility between gear-shaft and rotor is achieved by using a quill shaft. The gearshafts and compressor rotors are carried on white metal turbine-type bearings, while double-acting thrust bearings of the Michell type locate the rotors and take care of end thrust. This thrust is caused by the pressure difference which results from the inlet and outlet ports being situated at opposite ends of the rotors. The glands consist of a carbon pack, and are so arranged that the air pressure helps to seal them. Any slight leakage of air passing the first section of the glands is vented away to atmosphere.

Forced-feed lubrication is supplied to all bearings and the gears, from an oil pump driven from the slow-speed shaft of the speed-increasing gear. The oil is circulated through a water-cooled oil cooler, then through an oil filter of the felt or gauze type. The lubricating system also supplies cooling oil to the two rotors, which is fed through the hollow rotors by nozzles. Cooling is necessary because the machine is of the axial-flow type, which causes differential expansion as the rotors at one end are subjected to the full heat of compression. Throwers are provided to prevent oil finding its way to the glands and the cylinder. The rotors are not lubricated externally and the machine delivers oil-free air.

Figure 6 shows how compression takes place by the meshing together of the two rotors, the suction port being suitably designed to open up some of the lobes

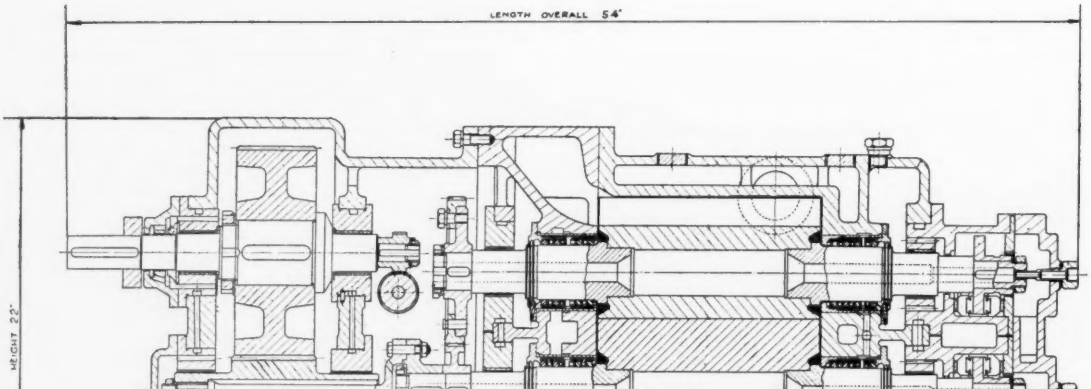


Fig. 5—Sectional arrangement of single-stage screw-type compressor

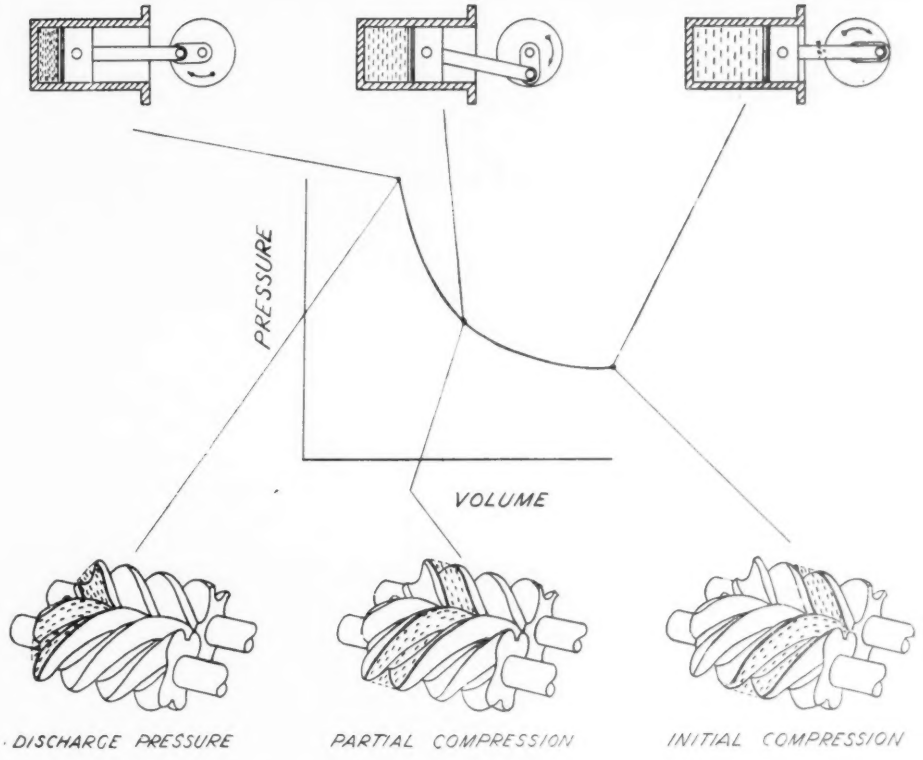


Fig. 6—Details of meshing rotor, screw-type compressor

to atmosphere as they pass. Once past the port, the lobes seal the trapped air which is compressed and the rotors mesh until the air reaches roughly the designed pressure when it is released into the discharge port. The helical wrap (i.e. the angle through which each lobe turns in the rotor length) is usually 300°, which ensures that the suction and delivery sides of the compressor are always sealed off from each other by the lobes, thus preventing leakage from pressure to suction side.

As the amount of air passing through the clearance between any two components is constant at a given pressure, it follows that the rate of leakage will not vary unduly, whatever the speed of the machine. Full advantage is taken of this, and by designing on high rotor-tip speeds (which average 350 ft/s), the leakage loss is low in relation to the output, and volumetric efficiencies are high. Because of the absence of rubbing parts, the mechanical losses are confined to bearing friction and gear losses, so that mechanical efficiency is also high. The cylinder is water-cooled, but because of its small size and large output due to high speed, the cooling effect is negligible and the water jackets mainly serve to even out expansion of the cylinder. Therefore during compression the air is virtually uncooled, air-leaving temperatures are high, and compression is adiabatic. There are also pressure losses in inlet and outlet ports because of the high velocities, and these air losses together with the adiabatic compression tend to offset the high volumetric and mechanical efficiencies.

Single-stage compressors are built in four sizes with outputs varying between 400 and 8000 ft^3/min, the smallest machine running at 9000–18,000 rev/min and the largest at 1500–4500 rev/min. Variations in output are obtained by changing the speed of the driving rotor within the above limits, and with each frame size the highest efficiency is attained at its top speed. Single-stage machines are suitable for pressures up to 60 lb/in^2, but the best efficiencies are achieved with working pressures not exceeding 35 lb/in^2.

Figure 7 illustrates the typical characteristic curves for the 800–2000-ft^3/min machine whose speed range is 6000–12,000 rev/min, whilst Fig. 8 shows the b.h.p./output curves for this same machine and for the smallest frame size, which has an output range of 400–725 ft^3/min.

These compressors are very compact and Fig. 9 shows the 800–2000-ft^3/min machine, without its oil-cooler and bedplate. Its length is 54 in. and as illustrated it weighs only 12 cwt.

Two-stage compressors are arranged with the high-pressure and low-pressure rotors mounted in tandem on a single pair of shafts, which reduces the overall

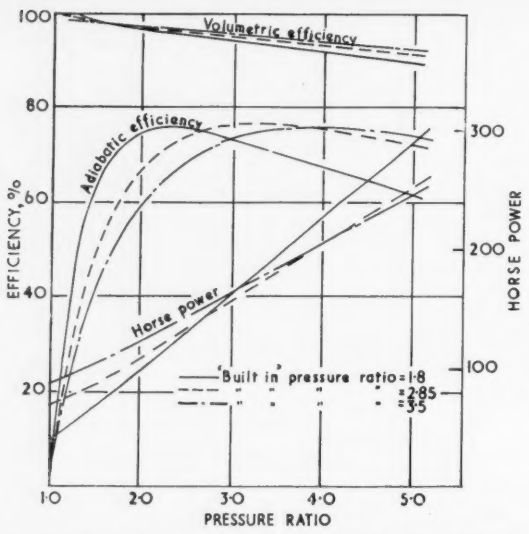


Fig. 7—Typical characteristic curves for 800–2000 ft³/min, single-stage screw-type compressor

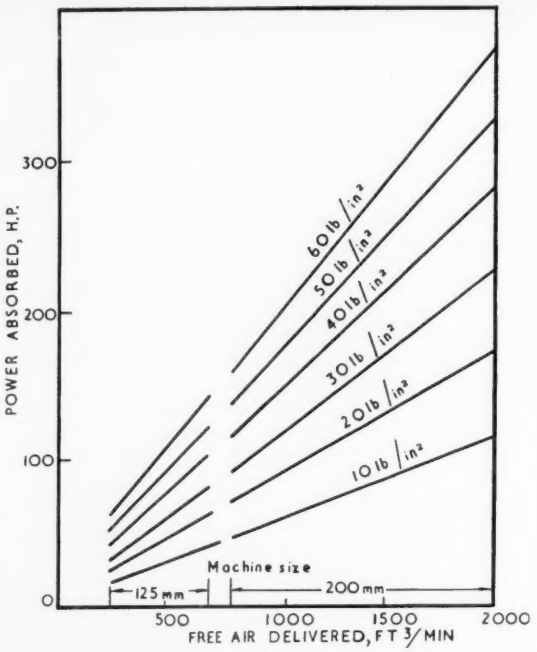


Fig. 8—Diagram of b.h.p./output curves for single-stage screw-type compressors, 125-mm and 200-mm machine sizes gnly

size of the machine as illustrated in Fig. 10. Four frame sizes are available, which cover outputs between 400 and 8000 ft³/min and pressures up to 150 lb/in². Outputs up to 2000 ft³/min are catered for by the two smallest frame sizes. Figure 11 shows the performance curves for these machines which run at 9000–18,000 rev/min and 6000–12,000 rev/min respectively.

Each machine includes water-cooled intercooler, oil cooler, oil filter, and inlet and outlet silencers which reduce noise to normal engine-room level. Air filtering is desirable but in some cases is not considered essential.

When applied to gas, this type of compressor is virtually unchanged, with the exception of the gland vent which is piped back to the suction main. There is, however, a loss of output due to the reduced density of the gas, the amount varying with the pressure and averaging about 7%. With this design, construction materials can be varied to suit the particular application.

Oil-flooded Rotary Compressor

This type is a comparatively recent development, and the machine described has been designed for use as a portable compressor. It is claimed that it is smaller, weighs less, is more silent in operation, and the power required is lower than for the air-cooled piston-type portable unit which it replaces.

Figure 12 shows a section through a two-stage compressor which is directly driven by a diesel engine at 1825 rev/min through a safety friction drive which transmits full engine power and protects both compressor and engine shafts by absorbing shocks automatically. The two stages are arranged in tandem and are coupled together by a dog-type flexible coupling which enables the rotor shafts to expand without setting up undue end-thrust. Both rotors are mounted eccentrically in the cylinders and are slotted for eight non-metallic blades which fly out due to centrifugal force, and are contained by the cylinder walls. A rotary shaft-seal is used at the driving end of the first stage cylinder to prevent loss of oil and to protect the shaft bearings from dirt. The first- and second-stage cylinders and rotors differ only in length, those of the second stage being shorter due to the smaller volume of the intermediate pressure air going forward to the second stage. Both rotors are mounted on shim-adjusted tapered roller bearings which position the rotors endwise.

The two holes in each segment of the rotors are drilled at an angle into the bottom of the blade slots, i.e. two holes to each slot. Their purpose is to allow

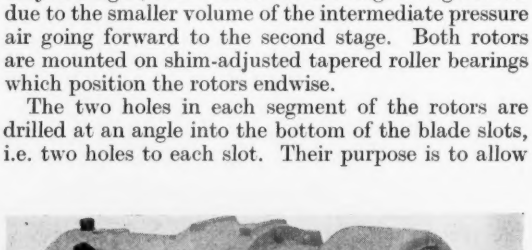


Fig. 9—Screw-type compressor, 800–2000 ft³/min capacity

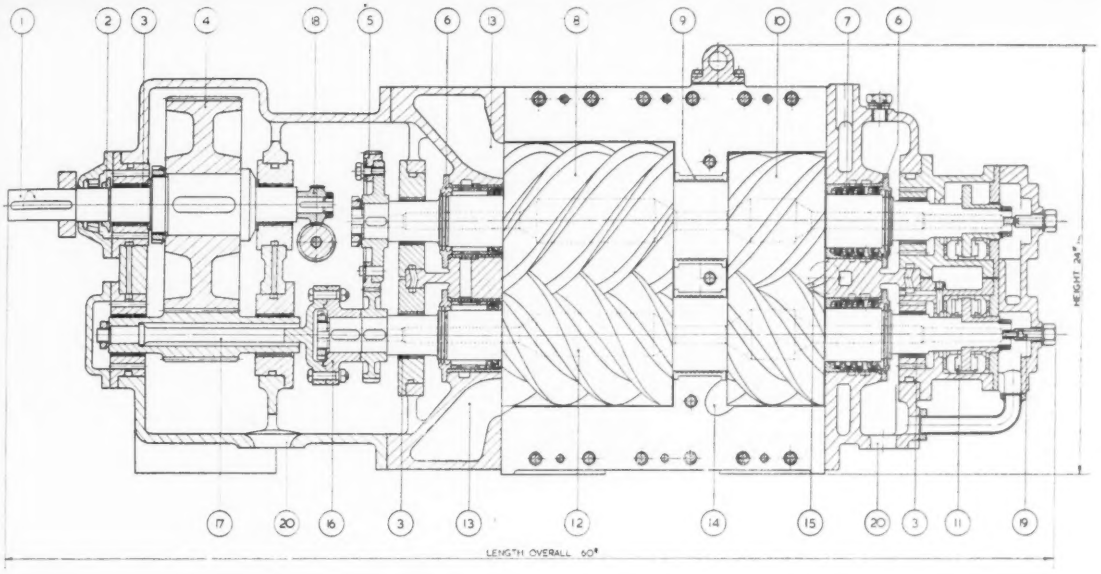


Fig. 10—Sectional arrangement of 1000–2000 ft³/min two-stage screw-type compressor

free flow of air and oil to or from the space underneath the blade, dependent on whether the blade is moving into or out of the slot. It will be noted that the first-stage rotor is mounted at the top of the cylinder, whereas the second-stage rotor is mounted at the bottom. With this arrangement a more compact layout is achieved, i.e. the discharge branch of the first stage is on the same side of the machine as the suction branch of the second stage, a point clearly illustrated in Fig. 13.

To prevent reversed flow of air when stopped, a simple plate-type non-return valve is connected to the second stage discharge branch and, to facilitate re-alignment after dismantling, all castings are spigotted.

A gear-type oil pump, driven direct from the shaft of the second-stage rotor, supplies copious quantities of oil which has three functions: lubrication, cooling, and sealing of clearances. Oil is fed direct to the bearings and is injected into the cylinders, on the suction side, where it mixes with the air while orifices proportion the quantity of oil flowing to the different components. The cooling effect of the oil limits the temperature-rise of the air by absorbing the heat of compression, and neither interstage cooling nor water-cooled jackets are required.

Air enters the compressor via the oil-bath-type air filter and the suction unloading valve, and is compressed in the first-stage cylinder. The oil-cooled air and oil then pass forward to the second stage for final air compression to the required pressure. The discharge ports are designed so that the air pressure when released by the port is about equal to the working pressure.

The air and atomized oil pass forward to the air receiver where about 99% of the oil is separated out and returns to the oil tank, final oil separation taking place in a labyrinth oil separator while the recovered oil is drained back to the suction side of the second stage. With the method of oil separation used, it is claimed that the percentage loss of oil is extremely small, and is in any case less than that normally expected with a portable compressor of the piston type.

Down to half speed, output is controlled by an air-operated variable-speed throttle, followed by a pilot valve which becomes active at about half engine-speed, gradually admitting air to the suction control valve which shuts off the air intake. In the case of constant-speed drive, the throttle controller is connected to the intake air valve which gradually varies the suction pressure and hence the compressor output. There is no air-release to atmosphere, and when the

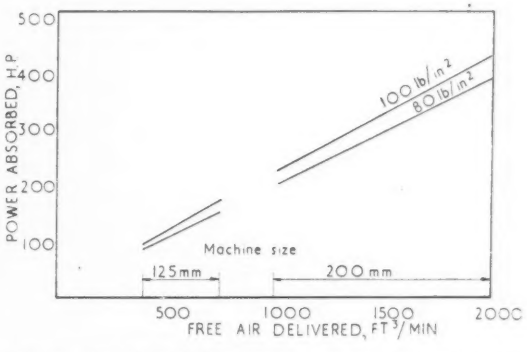


Fig. 11—Graph of b.h.p./output curves for two-stage screw-type compressors, 125-mm and 200-mm machine sizes only

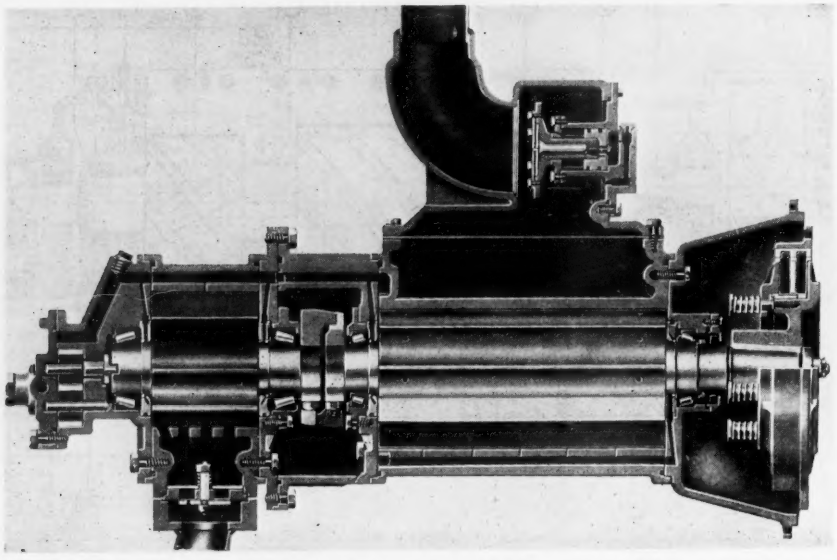


Fig. 12—Sectional view of two-stage oil-flooded compressor, 125-mm and 200-mm machine sizes only

machine is under vacuum due to intake closure, oil is still circulated and keeps the machine cool in spite of the very high compression ratio.

Figure 14 shows a 365-ft³/min, 100-lb/in² two-stage compressor driven by a four-cylinder diesel engine at 1825 rev/min. The radiator is a combination unit, the front core being the compressor oil-cooler, and the rear section the engine water-cooler. The total weight of the complete unit is 7880 lb.

Two-stage portable units of this type are available in five sizes, with outputs varying between 120 and 600 ft³/min for pressures up to 150 lb/in², and all have been suitably designed for operating with ambient temperatures up to 125° F.

Restraining-ring Compressor

This type may be termed ' the orthodox high-pressure rotary.' It is a well-proved design which continues to gain ground, and large numbers are built in the U.K. and on the continent. The design has not neessarily reached its optimum, however, and development work continues.

Figure 15 shows a sectional arrangement of a typical single-stage, water-cooled machine. The rotor is formed from a cast-iron block shrunk on to a steel shaft and slotted for 18 high-tensile steel rotor blades before final precision grinding. It is mounted eccentrically on heavy-duty roller bearings in the cast-iron casing, and is free to float endwise. The bottom

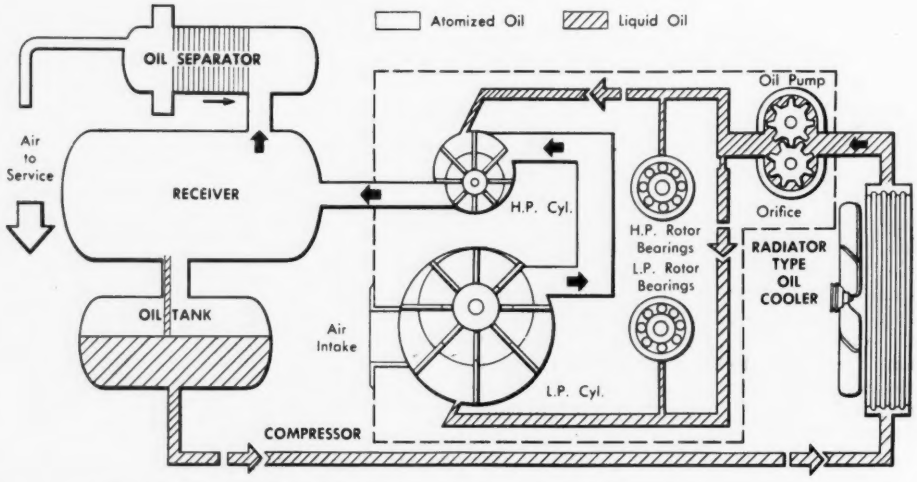


Fig. 13—Diagrammatic arrangement of two-stage oil-flooded compressor

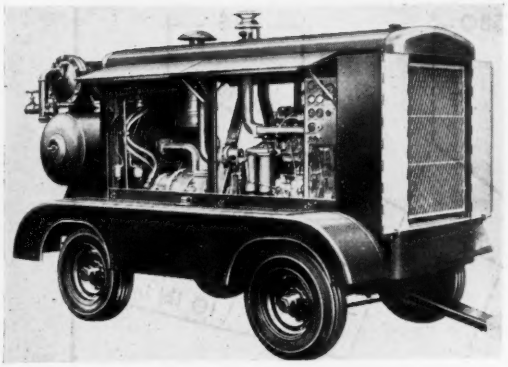


Fig. 14—Two-stage oil-flooded compressor, diesel-driven at 1825 rev/min, delivering 365 ft³ at 100 lb/in²

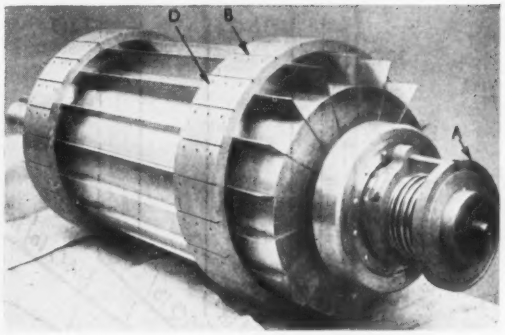


Fig. 16—Complete rotating element, restraining-ring-type compressor

clearance is arranged so that the rotor is free of the cylinder when the machine is warmed up. The end covers are permanently dowelled to enable the compressor to be dismantled without losing the original setting.

Figure 16 illustrates the complete rotating element, and the gland shown is of the metallic type. The various cast-iron details are hand-lapped together, all gland parts revolve with the shaft and the only relative movement is between the washer '*A*' and the gland housing. With this type of gland there is no scoring of the shaft and consequently no wastage of power.

Lubrication is by direct-coupled mechanical lubricator to four or six points according to the size of machine, and the oil supply to the glands also lubricates the bearings and eventually passes through the covers and assists in the internal lubrication of the compressor.

A non-return valve is provided which is always open when the machine is compressing and serves to protect the machine against a reversal of air flow when stopped or running light.

The restraining rings are the essential feature of this design. They are free to rotate when driven by the main blades which fly out under centrifugal force, their function being to support the blades. They are machined slightly smaller in the bore than the cylinder and proportioned so that under working temperatures the blades are restrained and cannot transmit heavy loads to the bore of the cylinder. The rings must be in air-balance, and this is achieved by the small blades '*B*' and the holes '*D*' (Fig. 16) which make it possible for the different pressures around the machine to be equalized at the back of the rings. With this arrangement the rings run concentrically with the cylinder and are not forced over towards the suction side by the compressed air. Furthermore the restraining-ring blades prevent loss of air from pressure to suction side around the rather large diametrical clearance between ring and cylinder.

The peripheral speed of the blades is varying each revolution (the highest tip speed occurring at the top of the cylinder), whereas the restraining rings must take up an average speed and with each revolution there is therefore a small amount of relative movement between the rings and main blades which ultimately causes wear.

Referring again to Fig. 15 (end view), the segments formed by the blades between points *E* and *F*

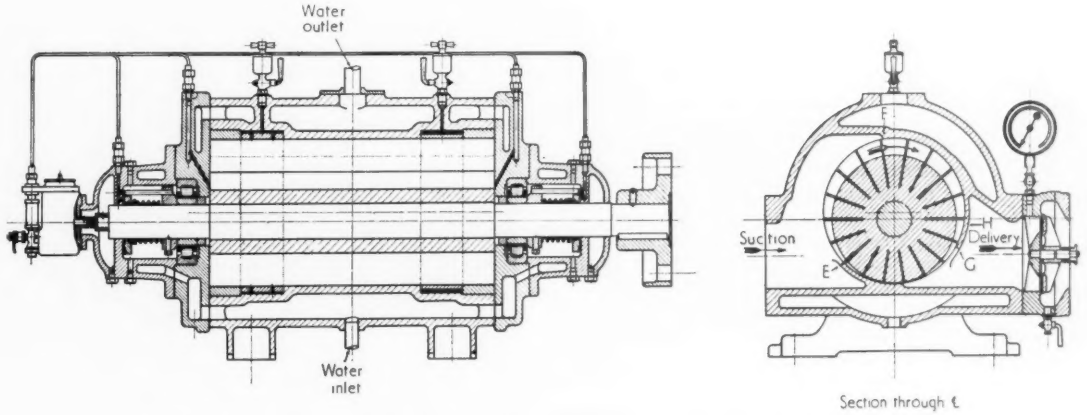


Fig. 15—Sectional arrangement of single-stage restraining-ring-type compressor

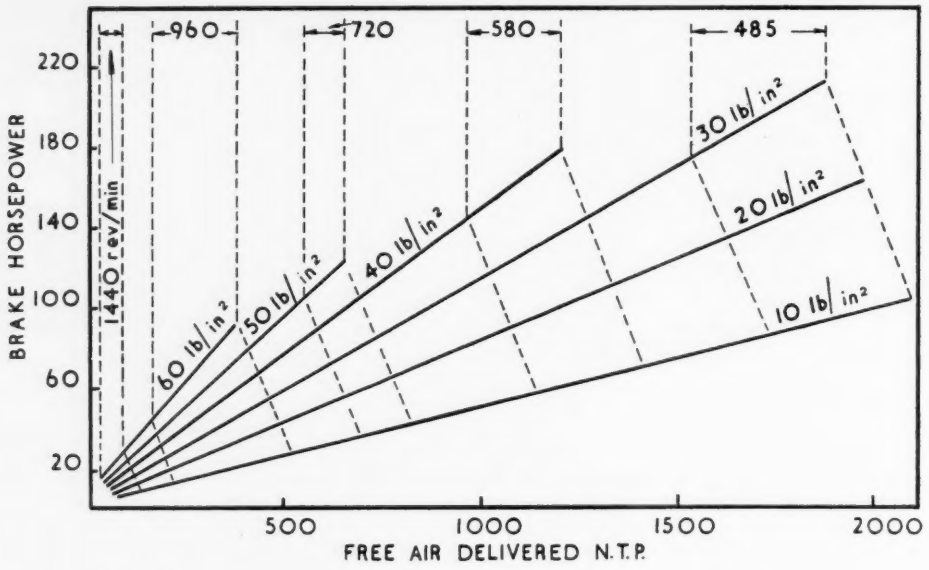


Fig. 17—Performance curves for single-stage rotary compressors, restraining-ring type

are open to atmospheric pressure, and compression does not commence until the individual cells pass point *F*, after which it continues progressively to the release point *G*, when the compressed air is released into the discharge branch. The port which is formed by the skirt *H* is the point of release, and the distance of this above or below the centre-line determines the amount of internal compression. The depth of the port is arranged so that the cell pressure at the point of release is about equal to the required working pressure. The position of the suction port *E* controls leakage, and its distance below the centre-line is varied to suit the working pressure. This ensures a controlled expansion (down to suction pressure) of the air passing under the rotor and minimizes loss of air by reducing the pressure difference at the point of leakage. Correctly designed suction and delivery ports ensure quiet running and silencers are not required.

In Fig. 15, the rotor is slotted for 18 blades, of which six are utilized in the compression zone above the discharge port. This minimizes the pressure difference between segments as well as the side pressure on the blades. Furthermore air leakage between cells is reduced and a continuous flow of air, free from pulsations, is achieved.

When designing rotary compressors the governing factor is the permissible tip speed of the blades inside the cylinder walls, for the number of times per minute the blades move in and out of the slots is not critical. Figure 17 shows the performance curves for the complete range of single stage machines, all of which have similar tip speeds. By selecting suitable cylinder bores consistent with the permissible tip speed, it has been possible to make available a full range of compressors suitable for direct coupling to a.c. motors.

It will be noted that as the outputs increase, the maximum working pressure is reduced. This is necessary because the larger the machine the more difficult it is to transmit the required amount of heat to the cooling water. The cross-sectional area of the cells for a large machine is much greater than that for a small unit, and as the tip speeds are similar, it follows that a smaller proportion of the air passing through the large machine is cooled by contact with the cylinder walls. This point may be illustrated by considering two machines, one of 100 ft³/min and the other of 2000 ft³/min capacity, operating at 30 lb/in² with 60° F ambient temperature. With the small machine, the air-leaving temperature would be 225° F, and 285° F with the large one. A single-stage water-cooled compressor driven by an a.c. motor is illustrated in Fig. 18.

Two-stage compressors may be used with advantage for the 50 and 60 lb/in² duties, particularly in the case of large outputs. This point will be referred to again.

Air-cooled machines are available for working pressures up to 15 lb/in² and outputs up to 2000 ft³/min.

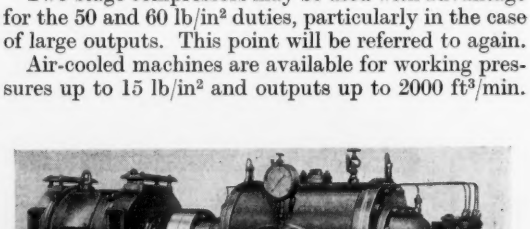


Fig. 18—Single-stage restraining-ring-type compressor

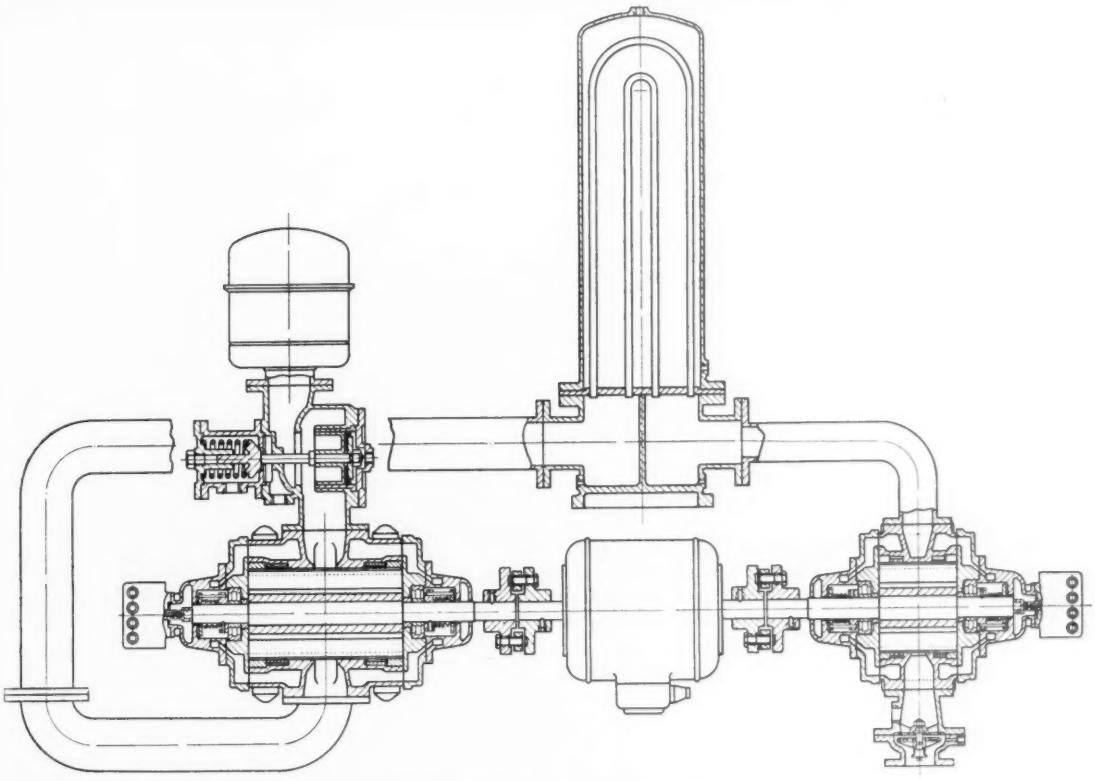


Fig. 19—Sectional arrangement of two-stage compressor

By designing to suit the low pressures, performance figures are rather better than those for water-cooled machines on corresponding duty.

Figure 19 shows the sectional arrangement of a two-stage, water-cooled compressor. Air enters the first-stage compressor via the oil-bath-type filter and the automatic suction control valve, and after compression it is cooled to about 100° F by the intercooler before passing forward to the second stage for final compression.

The two stages of the compressor are very similar but the second stage is shorter and has 24 main blades whereas the first stage has 18. The machine is designed so that when operating at 100 lb/in², the air-leaving temperatures from both stages are about equal. This results in an intermediate pressure of about 30 lb/in², and therefore the second stage has a pressure difference between inlet and outlet of 70 lb/in², hence the reason for the six additional blades.

The intercooler is of the four-pass type, the air flowing through hairpin tubes which are expanded at both ends and allow differential expansion due to temperature. The air head is provided with three drains from which a substantial proportion of the oil and water from the air is blown off. The cooling water enters at the bottom of the cooler and leaves at the top, and by removing the steel cover the tubes are exposed and can be cleaned by brushing. The cooling of compressed air is a difficult problem, but with the cooler described, the highest possible transmission rate is achieved by passing the air through the tubes, at a suitably designed velocity. A non-return valve is provided with the second stage, and this prevents reversed flow of air when the machine is stopped or is running light.

The two stages are normally arranged one on either side of the driving motor, with the resultant advantage that only half the power has to be transmitted by each compressor shaft. This layout also facilitates access, and for inspection purposes it is possible to remove the end covers from both stages without disturbing the alignment or the piping. Flexible couplings of the leather-link type are used, and these are specially designed to absorb the expansion of the compressor shafts without causing excessive end-thrust.

As the rotors are air balanced, thrust bearings are not required, and the end clearances of compressors having outputs above 500 ft³/min are arranged so that, under working conditions, the end-float in each stage is not less than 0·01 in. The shaft of the driving unit must, however, be located.

Figure 20 shows a 1060-ft³/min, 100-lb/in² compressor, driven by an a.c. motor at 580 rev/min, and it will be noted that the intercooler is arranged at the end of the machine. This makes a compact layout with the minimum of interstage connecting piping but the floor space required tends to be long and narrow.

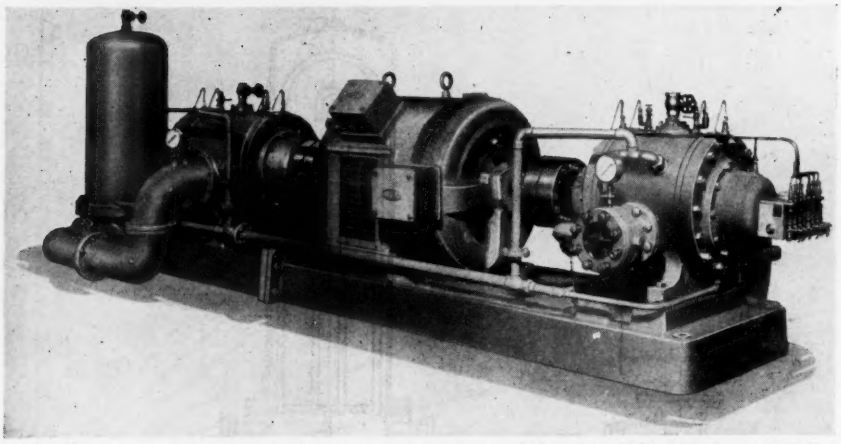


Fig. 20—Two-stage restraining-ring-type compressor delivering 1060 ft³/min at 100 lb/in²

Where space is limited, the machine can be shortened by arranging the intercooler at the side of the bedplate.

Figure 21 gives the speeds, range of outputs available, and performance data for two-stage compressors at 80 and 100 lb/in². For comparison purposes, efficiencies are shown on both the isothermal and adiabatic basis.

Figure 22 shows the comparison between single and two-stage compressors at 60 lb/in² (a pressure frequently used for sand- and shot-blasting plants) and illustrates the technical advantage of using the two-stage unit. The air-leaving temperatures for a single-stage compressor would be about 330° F whereas the leaving temperature on both stages of a two-stage machine would not exceed 220° F. The two-stage

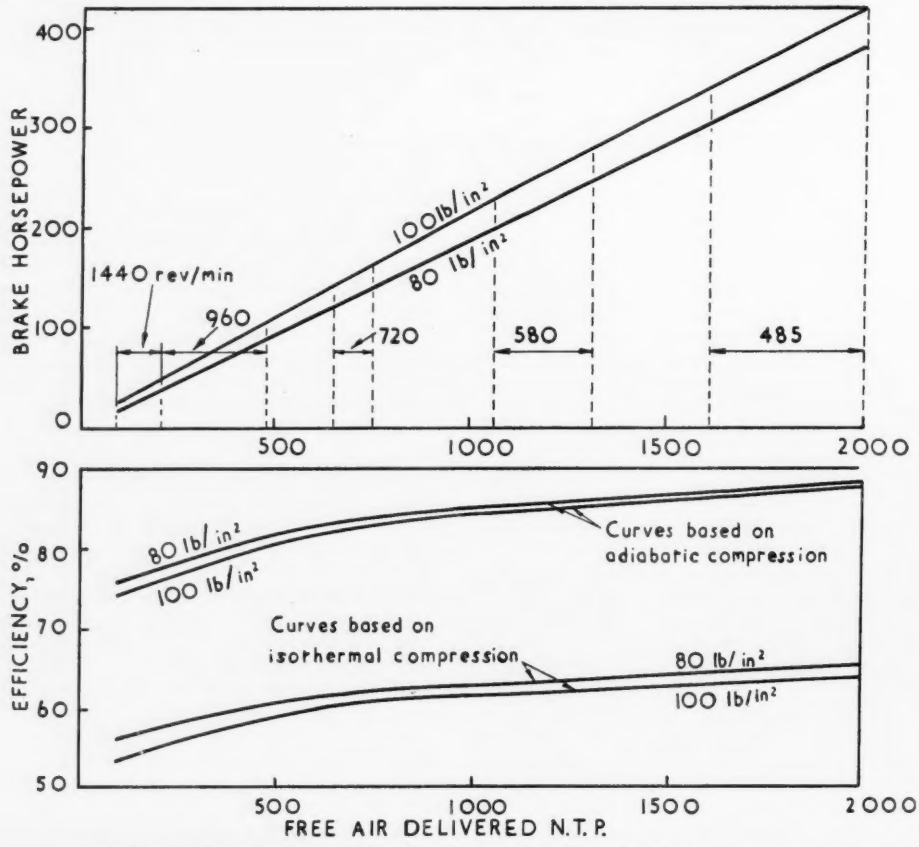


Fig. 21—Performance curves for two-stage restraining-ring-type compressors

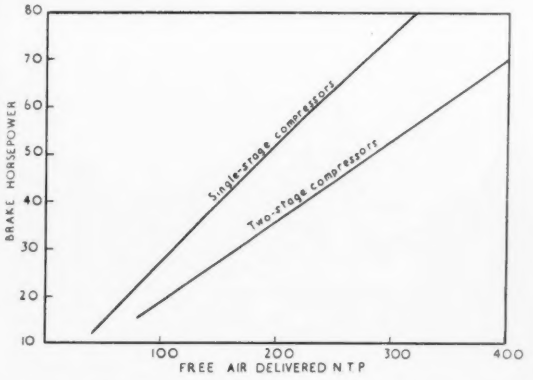


Fig. 22—Performance curves for single and two-stage, restraining-ring-type compressors at 60 lb/in² pressure

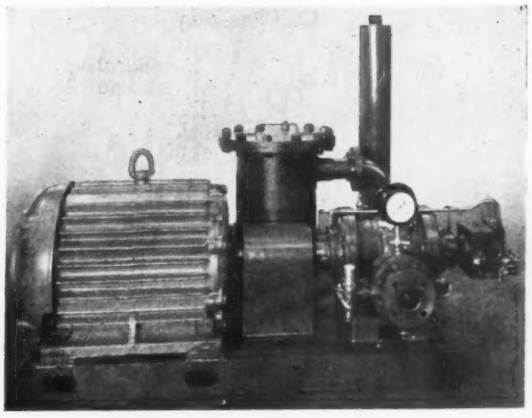


Fig. 24—Air-cooled booster, 500 ft³/min free-air capacity

unit is therefore more reliable but it requires more space and the first cost is higher.

Figure 23 illustrates three 750-ft³/min, 80-lb/in² compressors installed at a tube works, and in the background can be seen two small, air-cooled compressors which maintain a 120-lb/in² service by boosting compressed air from the 80-lb/in² main.

As in the above case, it frequently happens that there exists a demand for compressed air at two different pressures, and usually the amount of air required at the top pressure is small when compared to the total. As an example of the economy in power which may be achieved in these circumstances, the case may be considered where a total of 2000 ft³/min of free air is called for, of which 1500 ft³/min is required at 80 lb/in² and the remainder at 120 lb/in².

To compress 2000 ft³/min to 80 lb/in² requires 370 b.h.p., and to 120 lb/in² about 460 b.h.p., whereas a booster compressing 500 ft³/min of free air from 80 to 120 lb/in² requires 26 b.h.p., so that the net saving is about 64 b.h.p. Additional advantages are that the main compressors have less work to do and the air temperatures are lower, with a consequent increase in reliability.

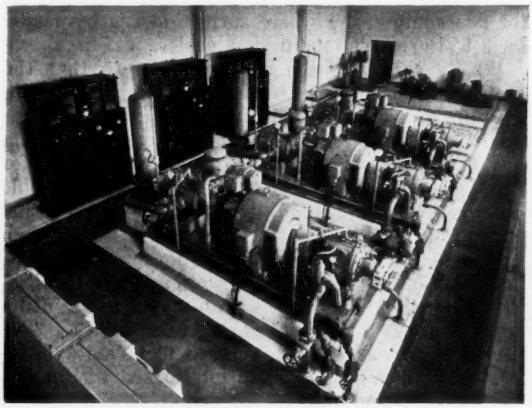


Fig. 23—Two-stage compressors and boosters installed in a tube-works

Air-cooled machines can be used for this service because the heat generated by friction bears a definite relationship to the size of the machine. It follows that the large amount of free air passing through the relatively small booster can absorb the heat generated by friction and compression without excessive increase in temperature. In the example discussed, the temperature-rise across the machine would not exceed 100° F.

Figure 24 illustrates a 500-ft³/min air-cooled booster having a displacement of 100 ft³/min and running at 1440 rev/min. It has a pipeline filter with combined water separator on the inlet side and an unloading valve, while a silencer deals with the small amount of air blown to atmosphere when the machine unloads. The machine is compact, its first cost is low, and the additional cost of the 460-h.p. motor required for the main unit at 120 lb/in² covers a large proportion of the capital outlay for the booster and its motor.

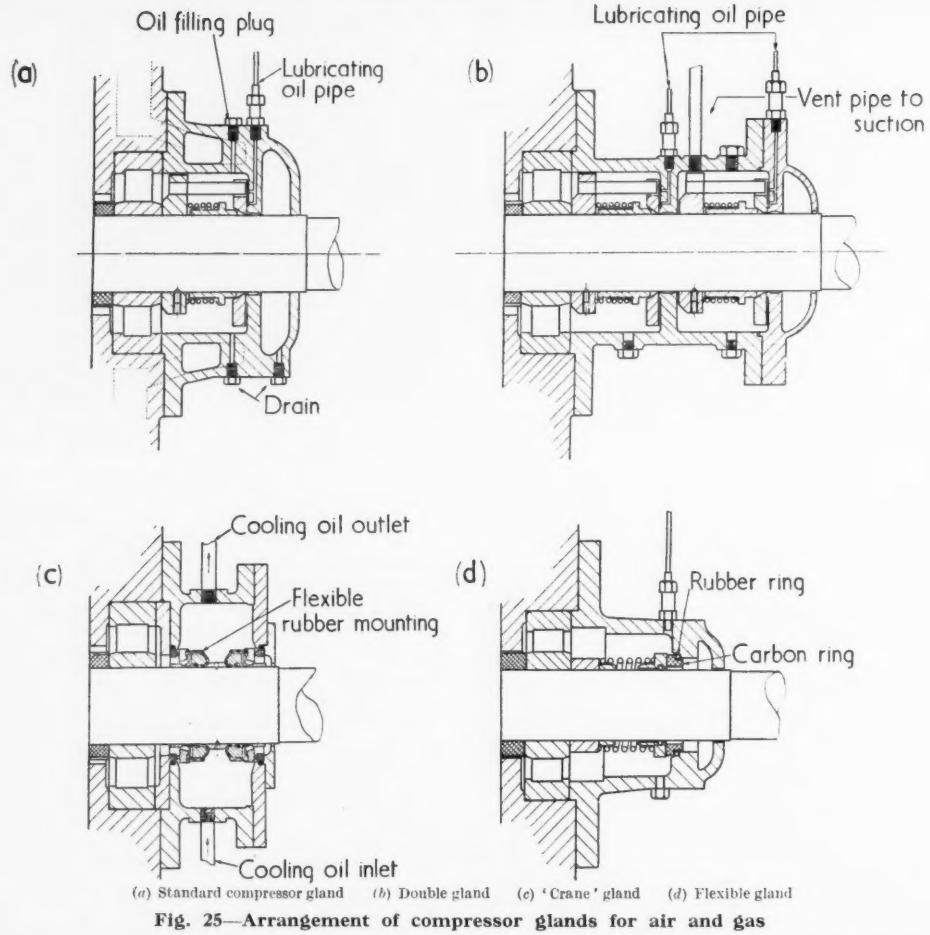
An essential safeguard is the fitting of a pressure-controlled relay which prevents the booster being started until the suction pressure has been established, and shuts it down if suction pressure falls below a predetermined safe minimum. When considering the size of a booster, it is necessary to ensure that its output includes a good margin over the potential air demand. If the output is less than the demand then the booster acts as a reducing valve.

The restraining-ring type compressors are suitable for use as gas compressors, provided that the gas is clean, non-corrosive, and does not contain undue quantities of solvent which would impair the quality of the lubricating oil. When compared to those for air, the output figures are slightly reduced due to the lower density of the gas, the power remaining the same. The machines have been extensively applied to coal gas, inert gas, and the refrigerant gases ammonia and freon.

Figure 25 illustrates four different types of glands which are used on gas compressors.

(*a*) The standard compressor gland, which is also suitable for inert gases and for relatively low-pressure coal gas

(*b*) A double gland of similar design to (i) in which



(*a*) Standard compressor gland (*b*) Double gland (*c*) 'Crane' gland (*d*) Flexible gland

Fig. 25—Arrangement of compressor glands for air and gas

any gas leaking past the first gland is vented back to the suction, the pressure difference across the outer gland being practically nil. This gland has been applied successfully to ammonia and to toxic gases.

(*c*) The 'Crane' flexible metallic packing in which a **U**-section rubber ring gives flexibility to one of the seal faces, thus counteracting any misalignment between shaft and gland housing. The gas pressure assists the sealing action, as does the oil which is fed to the housing for cooling purposes. Without the coolant, the life of the seal would be limited by the temperature effect on the rubber. This gland has been applied to refrigeration work, particularly in connection with installations using the costly refrigerant freon.

(*d*) The 'Flexibox' gland has a flexible seating, the carbon gland-ring being mounted on a rubber ring. The gland is driven round by the spring, which has an interference fit on both shaft and ring.

It is claimed that this gland is perfectly self-aligning, and that owing to the spring drive, side thrusts cannot develop. In cases where gas temperatures are high, oil is fed to the housing as a coolant. This gland has also been used in connection with refrigeration work.

METHODS OF UNLOADING AND CONTROL

There are four methods in normal use for controlling the amount of air delivered to a system by a rotary air compressor.

(1) By means of a relief valve which is arranged to open when the pressure reaches the required figure, the surplus air being blown to atmosphere. It is wasteful of energy except in the case of low-pressure machines, where light load losses are very little less than the normal load. This method is frequently used for gas compressors where surplus gas is by-passed back to the suction main via a cooler.

(2) By arranging the electrical gear so that the motor is started and stopped by a fall or rise in pressure as required. This method is used where the air load may be reduced for prolonged periods, e.g. day and night shifts. It is particularly suitable for installation with a rotary compressor, as the principle on which the machine works enables the usual expensive unloading valve to be dispensed with on machines up to 750 ft^3/min. The starting torque against the motor is a small fraction of the full load figure, as the blades do not begin to function until a speed of about 40% of normal has been attained. The electrical gear is usually designed to be suitable for up to 40 starts per hour and interlocked with it is a solenoid-operated water isolating valve which shuts off the flow of cooling water when the machine stops. Without this valve the compressor would be subjected

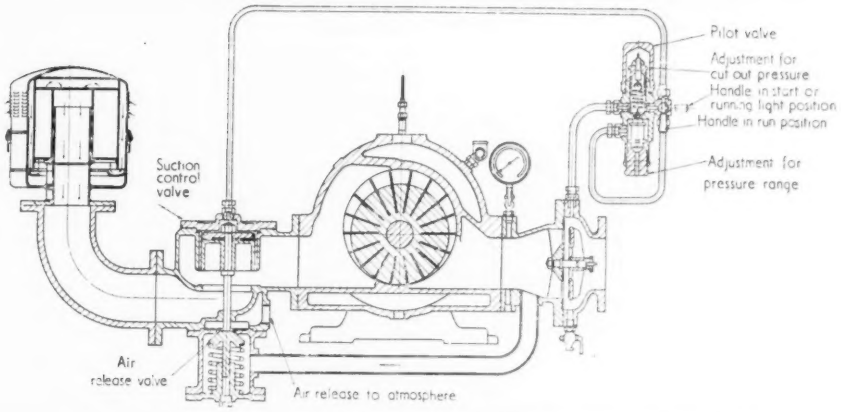

Pilot valve
Adjustment for cut out pressure
Handle in start or running light position
Handle in run position
Adjustment for pressure range
Suction control valve
Air release valve
Air release to atmosphere

Fig. 26—Arrangement of automatic suction control valve and pilot valve

to alternate expansion and contraction due to changes in temperature. The electrical gear is expensive but where conditions are suitable the extra cost can be quickly recovered. A large air-receiver is advisable with this type of control to minimize the number of starts and stops and the consequent wear and tear on machine and motor.

(3) By driving the compressor by a variable-speed drive such as a d.c. motor, variable-speed a.c. motor, variable-speed gear, or steam engine. These methods are very economical, as the h.p. required is directly proportional to the speed but there is a slight reduction in volumetric efficiency at the lower speeds. The lowest permissible speed with blade-type compressors is 60% of normal, as the blades do not function satisfactorily below this minimum speed.

(4) By closing the suction of the compressor so that no appreciable amount of air is passed through it. This method is the one most frequently used where the air demand normally absorbs a large proportion of the potential output of the compressor, i.e. the time compressing will be substantially greater than the total time running light.

A typical automatic suction control valve and pilot valve as used for method (4) is illustrated in Fig. 26. Operation of the valve is effected by the high-pressure air, which is controlled by a pilot valve fitted with a spring against which the pressure has to operate. When the delivery pressure exceeds the required figure, the pilot valve opens and admits air on to the top of the piston. This moves downwards on to its seating, thus shutting off the suction of the compressor from atmosphere. At the same time the release valve is opened. The underside of this valve is connected to the delivery of the compressor and, when opened, any air that may be inside the machine is discharged to atmosphere and the whole compressor runs under vacuum. The percentage horsepower absorbed at the compressor shaft when running light depends on the working pressure and, in the case of a 100 lb/in² two-stage restraining-ring compressor it is 20% of full load power.

When the pressure in the delivery air main has fallen by the required amount, usually from 5 to 12 lb/in², the spring on the pilot valve causes it to close. The space on top of the operating piston is opened to the atmosphere, and the spring opens the main valve and closes the release valve. The working pressure and the pressure range can easily be adjusted to suit individual requirements. To prevent overheating during prolonged periods of running under vacuum, a small amount of air is allowed to leak through the control valve to the machine. This is discharged to atmosphere through the release valve, and the slight reduction in vacuum does not increase the horsepower absorbed when running light.

In the case of large two-stage compressors, the air trapped in the machine tends to be momentarily noisy when vented to atmosphere. The pipe is therefore usually taken to the outside of the building, and when necessary the noise can be eliminated by a full-bore silencer.

Because of their low starting torque characteristics, rotary compressors are particularly suitable for coupling to squirrel-cage motors arranged for direct on-line starting. Manufacturers can design their motors to suit the favourable starting conditions, and by doing this, a smooth start and a low starting current are achieved. Power factor correction can be obtained by driving by auto-synchronous motor, and owing to the relatively high speed of the rotary compressor, the somewhat high cost of this very useful drive is correspondingly reduced.

MAINTENANCE AND ATTENDANCE

The following general remarks refer to compressors of the restraining-ring type and particularly to those installed in iron and steelworks, of which a large proportion are 1060-ft³/min two-stage machines operating at 100 lb/in².

It is difficult to lay down rules as to how often rotary compressors should receive routine maintenance, as so much depends on conditions which vary from factory to factory. Machines have been known to run continuously for periods up to seven years without opening up, but this is not recommended. Others have run up to 20 years and still have the original bores.

Subject to the air filter being cleaned regularly, the correct grade of oil being used, and the cooling water not rapidly forming scale, it is usually possible for a new two-stage 100-lb/in² compressor to run continu-

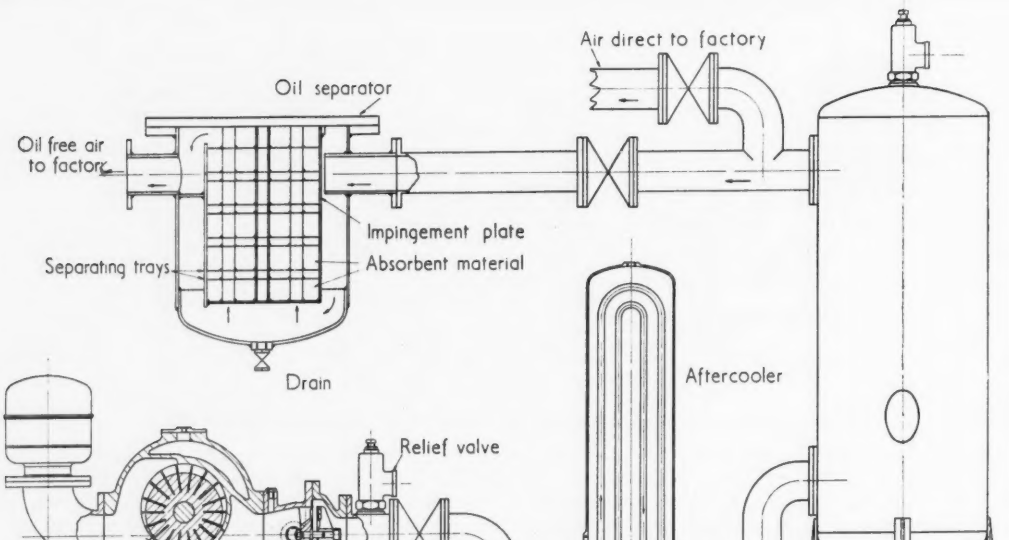


Fig. 27—Typical layout for oil separation

ously for two years or the equivalent number of hours, before requiring dismantling for cleaning and minor adjustments. Subsequent overhauls at similar intervals are advisable otherwise deposits accumulate in the machine which, if allowed to become excessive, may eventually cause wear.

The main blades, restraining rings, and bearings would normally have a minimum life of five years of continuous running. The bearings have a substantial factor of safety but occasionally one can prove defective and flake after a comparatively short life. The bearings fitted to a rotary compressor have additional radial clearance to allow for the expansion of the shaft and inner race because of the heat of compression. Bearings having standard clearances would seize up within a few minutes of starting up.

The cylinder bores can be allowed to wear up to about 0·01 in. before requiring skimming out, and when this is done the machine has to be reset and new dowels must be fitted. Machines can also be brought back to standard by the fitting of liners which are pressed in but this is not recommended for second-stage cylinders because the liner is short and, owing to the weakening effect of the ports, it has insufficient grip.

The greatest rate of wear takes place in the second stage of the compressor, due to the inherent moisture in the air after it has passed through the intercooler. Recently, an improved oil has been introduced containing an anti-wetting agent which it is hoped will minimize corrosion by damp air and water droplets.

The grade of oil recommended should be strictly adhered to, since it is a heavy mineral oil with characteristics which prevent it breaking down and forming gummy substances which would bind and accumulate dirt entering the machine with the air. The oil consumption of the 1060-ft³ two-stage compressor is about 6 pints in 24 h, and where machines have to run unattended for long periods the storage capacity of the mechanical lubricators is increased. For normal running it is usual to top up the lubricators once per shift. About 40% of the total oil used is recovered by the intercooler, the remainder leaving with the air.

The oil-bath-type air filters normally fitted require cleaning and refilling about once a month, but this can become necessary once a fortnight in particularly dusty atmospheres. For cement works it is sometimes necessary to clean the filter every two or three days.

The restraining rings should be checked for rotation every few days and this is done by opening the flushing cups whilst the machine is running light, when the rings can be heard revolving. Sticking restraining rings cause rapid wear, and the best insurance against this is to use the non-carbonizing oil recommended by the maker.

COOLING SYSTEMS

These usually consist of an external supply such as town's water or, alternatively, recirculated water with cooler, and in both cases the supply must be sufficient to ensure that the outlet temperature from each component of the compressor does not exceed 100° F.

When using town's water with an inlet temperature of 60° F (40° F rise), the 1060-ft³ two-stage machine would require 800 gal of cooling water per hour, which absorbs the heat equivalent of more than half the power input to the compressor. Therefore it is worth-

while trying to recover this low-grade heat by using the water again, for boiler feed or process work. It is advantageous to incorporate flow indicators in the three return pipes, besides a partial or no-flow switch which trips out the machine in the event of failure of the cooling water supply.

In these days of water shortage, recirculating systems are frequently employed. These usually comprise a small, forced-draught cooling tower with circulating pump, the make-up water being supplied via a float-controlled valve situated in the base of the tower. With this system the inlet temperature to the compressor is usually high so that additional water has to be recirculated, and with an inlet temperature of 80° F the rise would be 20° F and the amount circulated would therefore be 1600 gal/h. It is a simple matter to arrange an electrical interlock so that the circulating pump has to be started before the compressor, and as this system is a closed one, it is essential to have visual flow indicators in the three return pipes.

In cases where the cooling water is taken from a river and contains silt, compressed air connections are arranged on the cylinder, gland housings, and intercooler, and by occasionally blowing out the jackets, at the same time maintaining the flow of water, it has been found possible to move the deposits without dismantling, and thus to achieve very long runs between overhauls.

OIL AND WATER SEPARATION

In many applications the presence of lubricating oil in the compressed air is an advantage. It helps to lubricate air-operated motors and tools but in all such cases and in many other applications water in the air is a definite disadvantage.

For industrial purposes it is usual to limit dehydration of the air to that which can be achieved by aftercooling down to 100° F. To remove the remainder of the water would mean cooling down to about 30° F and necessitate using brine as the coolant.

Figure 27 shows a typical layout designed to remove oil from compressed air. It will be seen that the aftercooler and air receiver form the first steps in the process, and up to 90% of the oil leaving the machine can be removed by this means alone. To remove the remainder is a more difficult problem and subject to the air being cool, experience has shown that absorption-type separators give the best results. The separator shown has two passes, the first having an impingement plate for mechanical separation, the separated oil draining to the bottom of the vessel. The air then travels at low velocity up the other side of the separator through several layers of absorbent material arranged on trays to facilitate repacking, also to keep the layers apart. The pressure loss through the separator is normally $\frac{1}{2}$ lb/in^2, but without the separating trays the material would consolidate and the pressure loss would be much greater.

When operating continuously, it is usually necessary to repack about once a month and materials which have been used are Indian cotton waste, Stillite, fibreglass, and cellulose wadding. In cases where extreme importance is attached to oil separation, two oil separators are arranged in series, and therefore the second separator lasts for a considerable period without repacking and is a safeguard in the event of the first separator passing oil because of overdue maintenance.

It has been shown in this paper that machines of the positive rotary type are available which can meet all normal industrial requirements. For working pressures in excess of 150 lb/in^2, the reciprocating compressor is as yet the more suitable machine and for some time to come it may retain its superiority in this range. Within its own field, however, the rotary compressor gives exceedingly reliable service and will maintain its high efficiency for very long periods. It is essentially an industrial machine, and it is hoped that this paper will have made clear to those perhaps unfamiliar with its design, both its limitations, which are few, and its advantages, which are many.

Acknowledgments

The author's thanks are due to the following: Lieutenant-Colonel K. Reavell of Reavell and Co. Ltd.; Mr. W. Bailey and Mr. J. Roy of James Howden and Co. Ltd.; Mr. J. R. Quertier of The Consolidated Pneumatic Tool Co. Ltd.; and to his colleagues at Hick, Hargreaves and Co. Ltd.

Blowers for Use in Iron and Steelworks

By F. J. Potter and L. Duffy

Introduction

Historical

THE TURBO-COMPRESSOR now assumes an important role in a multitude of industrial processes and may be used for compressing almost any gas or vapour.

Compressors which were manufactured by Parsons as early as 1901 were of the bladed axial-flow type, and for some years these were successfully put to a number of uses, particularly for blowing blast-furnaces which had hitherto been blown by large slow-speed

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The authors are with C. A. Parsons and Co., Ltd.

SYNOPSIS

From a technical viewpoint, machines handling gases and vapour can be divided into positive displacement units employing some sort of piston, and dynamic machines which apply the principles of flow phenomena. In the positive displacement machine the delivery medium is compressed in an enclosed space by reducing the volume of this space, and then expelled on the discharge side. This class comprising reciprocating and rotary machines is used in general for small deliveries, but almost any pressure. In the dynamic machine, compression is effected by the acceleration of the medium and the conversion of its kinetic energy into pressure energy, while certain designs also make use of centrifugal acceleration. These machines are suitable for large capacities and medium pressures and may be of the radial, axial, or mixed flow types.

In this paper it is proposed to consider only the dynamic or turbo-type machine. 1354

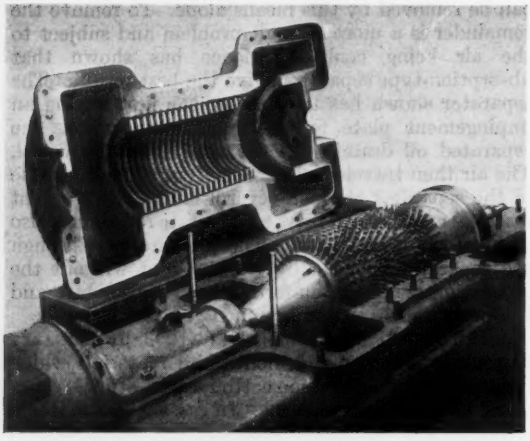


Fig. 1—First commercial axial-flow compressor, installed 1901

reciprocating engines. The blading in these early machines was a development of that used in steam turbines but as will be appreciated, in those days before the advent of aeroplanes little or nothing was known about aerodynamics, and in consequence the adiabatic efficiency was not high, being of the order of only 55–60%. Figure 1 shows the first commercial Parsons axial-flow compressor supplied to the firm of Cookson and Sons of Howdon-on-Tyne.

About the year 1907, radial-flow compressors were developed both on the continent and in the U.K., for running at speeds suitable for turbine drive. The much-improved efficiency, of the order of 70% adiabatic, obtainable at that date with this type of machine led to the manufacture of the radial-type compressor in place of the axial-type. That the flow pattern follows essentially different laws in the radial- and axial-flow types of compressor explains in a large measure the dissimilar course of development of these machines.

Compressor theory shows that in the radial impeller, a substantial part of the pressure rise originates from the centrifugal force imparted to the fluid by the vanes. In the axial-flow compressor, however, this effect is absent and the pressure rise takes place solely through the conversion of kinetic energy to potential energy.

The operation of compressing a fluid and maintaining a static pressure gradient, which in general opposes the flow, is far more sensitive to profiling than the opposite operation of expanding or accelerating. The former operation is dependent on the deceleration of the fluid relative to the stationary passage and the accompanying conversion of velocity energy into pressure. If for any reason the flow is not uniform or breaks away from the walls, then the velocity reduction cannot effectively take place.

Viscous effects cause the filaments near the boundaries to slow up relative to the main body of fluid and become deficient in energy. The adverse pressure gradient therefore tends to cause local reversal at the walls with consequent loss of pressure recovery. This may lead to serious breakaway which in some circumstances can cause complete reversal of flow.

When, at the turn of the century the centrifugal compressor was introduced and the axial-flow model fell into oblivion, this was entirely due to the radial impeller being much less sensitive to imperfect profiling. In recent years the further development of the axial-type compressor along the lines of modern aerofoil theory has resulted in efficiencies being obtained which equal and in many cases surpass those of high-class centrifugal compressors. This has resulted in its adoption as a counterpart of the modern gas turbine.

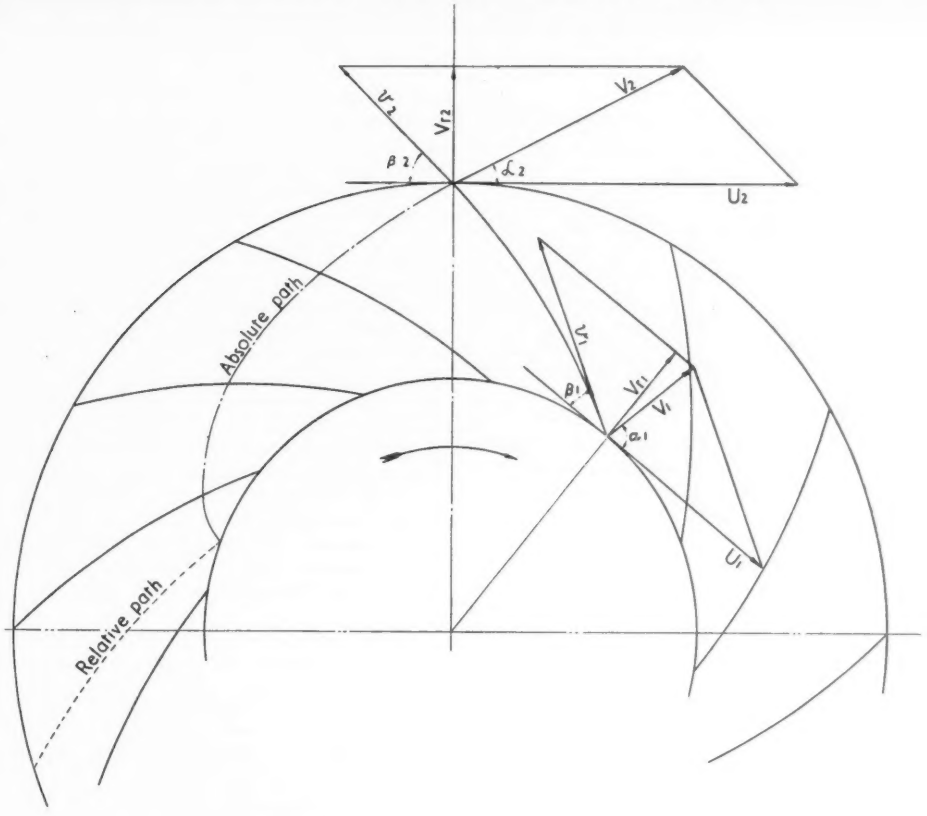
In their industrial application the two types supplement each other very well. The centrifugal compressor monopolizes the field of high pressures and medium flow, whereas the axial compressor is advantageous where relatively large delivery volumes are required at medium pressures and where in service the range of volume requirements is limited. As there is no general rule for the selection of centrifugal or axial-flow compressors it is advisable to compare the merits and drawbacks of the two types in each individual case.

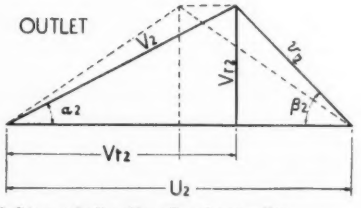
Extremely fine limits of accuracy are essential for good performance in an axial-flow compressor and it is here that the centrifugal compressor scores so heavily with its simple and robust construction. The sturdy impeller is practically immune to the effects of vibration, dirt, and abrasion, and continues to give unimpaired performance after many hundreds of hours service. An axial compressor, however, with its precise aerofoil surfaces and complex blade vibration problems is much more susceptible to the effects of dirt and abrasion and unless special means are adopted to ensure that clean conditions prevail, a gradual fall-off in efficiency can be expected.

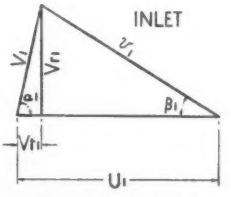
Turbo-blowers and turbo-compressors operate on precisely the same principle, and in practice there is no clear dividing line between the two types of machine. It has several times been proposed that some numerical definition should be set up, but the engineering world has not yet been able to agree on any generally accepted criteria, with the result that the distinction has remained merely a matter of usage. In general in this country, the term 'blower' is used to designate a machine compressing a large volume of gas to a comparatively low pressure, say to any pressure between 5-lb/in^2 and 50-lb/in^2 gauge, whilst turbo-compressors are machines compressing gases to higher pressures up to 150-lb/in^2 gauge.

THEORETICAL CONSIDERATIONS

A theoretical treatment of the flow through turbomachines is difficult because most of the channels comprising such machines have variable and irregular sections and a curved mean path. Some of the channels are in circular motion with power applied to or taken from the flow. If applied directly to such flow, simple relationships established in fluid mechanics for idealized conditions may give an incorrect answer. Centrifugal compressor theory, and the now classical theories of aerofoils and cascades are often simplified and then yield useful approximate values for the solution sought, but in cases where a theory based on physically sound assumptions is lacking, recourse must be made to systematic experimental investigation.







U ft/s = velocity of impeller at any radius
V_r = radial velocity of gas at any radius
v = velocity of gas relative to impeller
V = absolute velocity of gas relative to casing
V = tangential component of V
$\beta°$ = angle of vane at any radius
$\alpha°$ = angle of gas leaving vane at any radius

Fig. 2—Inlet and outlet velocity diagrams of impeller with backward-curved vanes

Assuming that the gas flowing through a rotating impeller exactly follows the impeller vanes, the inlet and outlet triangles of velocities for a radial impeller are shown in Fig. 2. U is the velocity of a point on the impeller relative to the casing, V is the absolute velocity of a gas particle flowing through the impeller relative to the casing, v is the velocity of a gas particle relative to the impeller, V_r is the radial component of the absolute velocity V, and V_t is the tangential component of V and equals $V \cos \alpha$.

The simple theory which is generally applied to turbo-compressor design is based upon three assumptions, none of which is exactly correct for actual units. These assumptions are

(i) The gas leaves the impeller passages tangentially to the vane surfaces, i.e. there is complete guidance of the gas at the outlet

(ii) The impeller passages are completely filled with actively flowing gas at all times

(iii) The velocities of the gas at similar points on all the flow lines are the same.

The head based on these assumptions is the ideal head and is obtained by applying the principle of angular momentum to the mass of fluid going through the impeller passages.

From the velocity diagrams in Fig. 2, $(w/g)V_{t_2}$ represents the force exerted by the fluid on the impeller. $(w/g)V_{t_2}$ is a force exerted by the impeller on the fluid and since torque = change of momentum per second,

$$\text{torque} = (w/g)(V_{t_2}r_2 - V_{t_1}r_1) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where w = fluid flow in lb/s

The power input P applied to the fluid by the impeller $= \frac{\omega w}{g}(V_{t_2}r_2 - V_{t_1}r_1)$.....(2)

or since $\omega = U/r$,

$$P = \frac{w}{g}(U_2V_{t_2} - U_1V_{t_1})\text{.....Eulers Eq. (3)}$$

Eliminating w from the above equation, the ideal head

$$H_i = \frac{1}{g}(U_2V_{t_2} - U_1V_{t_1})\text{ ft}$$

By geometric substitution from the velocity triangles

$$H_i = \frac{1}{g}(U_2V_2\cos\alpha_2 - U_1V_1\cos\alpha_1),$$

and $\quad v_2^2 = U_2^2 + V_2^2 - 2U_2V_2\cos\alpha_2$

$\quad v_1^2 = U_1^2 + V_1^2 - 2U_1V_1\cos\alpha_1$

$$\therefore H_i = \frac{1}{g}\left\{\left(\frac{U_2^2 + V_2^2 - v_2^2}{2}\right) - \left(\frac{U_1^2 + V_1^2 - v_1^2}{2}\right)\right\}$$

$$\therefore H_i = \frac{U_2^2 - U_1^2}{2g} + \frac{v_1^2 - v_2^2}{2g} + \frac{V_2^2 - V_1^2}{2g} \text{ .....(4)}$$

The head H_i is made up of pressure energy and of velocity energy. The static pressure increase given to the fluid by the impeller consists of the head created by centrifugal action which equals $(U_2^2 - U_1^2)/2g$ plus the head due to the difference in the relative velocities through the impeller $(v_1^2 - v_2^2)/2g$. Therefore the first two terms in equation (4) equal the static head at the impeller outlet and the last term $(V_2^2 - V_1^2)/2g$ is the increase in absolute velocity energy. An impeller operating at a given speed will develop the same head for any medium handled, as the head is expressed in feet of that particular medium.

In present-day designs, the axial-flow type tends to show a higher stage efficiency than the radial-flow type. Physically speaking, however, there is no reason why radial compressors should be inferior as regards efficiency. The ideal head equation shows that

$$H_i = \frac{U_2^2 - U_1^2}{2g} + \frac{v_1^2 - v_2^2}{2g} + \frac{V_2^2 - V_1^2}{2g}\text{ ft.}$$

For axial flow compressors $U_2 = U_1$ and the first term of the above equation is eliminated. Therefore, if with a radial design it were possible to convert the outlet kinetic energy $V_2^2/2g$ into pressure economically, it follows that for equal input-power the radial stage would give a higher pressure head than that of the axial stage.

To illustrate better the difference between absolute and relative velocities, Fig. 2 shows an impeller on which two paths of the same particle passing through the impeller are shown. The dotted line represents the path of the particle relative to the impeller and it is seen to follow the vanes as if the impeller were not rotating. The solid line represents the path of the particle relative to the casing due to the impeller rotation.

If the gas enters the impeller without a tangential component (radially for a radial impeller and axially for an axial flow impeller) V_{t_1} is zero and Euler's equation (3) reduces to $H_i = U_2V_{t_2}/g$ from which it is possible to draw some interesting conclusions regarding the head/capacity curve.

Consider the centrifugal stage. For a constant speed of rotation U_2 is constant and from the outlet velocity diagram Fig. 2 it is apparent that

$$H_i = \frac{U_2^2}{g}\left(1 - \frac{Vr_2}{U_2\tan\beta}\right)$$

Therefore if the flow of a given unit operating at constant speed is varied, V_{r_2} is the only factor in the above equation that will change. Since the outlet area of the impeller is constant, V_{r_2} will be directly proportional to the flow and the ideal head capacity curve will be a straight line. If the vane angle $\beta = 90°$, then $\tan\beta$ is infinity and the head must be constant at all capacities. Similarly, if β is less than 90° (backward-curved vanes), the head must decrease as V_{r_2} or the flow increases and if β is $> 90°$ the term $1 - (V_{r_2}/\tan\beta)$ becomes > 1 and the head increases with increased capacity.

Figure 3 shows the theoretical head/capacity curves and outlet velocity diagrams for various vane angles.

A secondary or circulatory flow, [1, 2] which depends upon the number and shape of the vane passages, takes place in a rotating impeller. The circulatory flow superimposed on the through flow has the effect of reducing the tangential component V_{t_2}, the velocity diagram being modified as shown by the dotted lines in Fig. 2. Other effects such as turbulence, friction etc. reduce the head and increase the power consumed under actual conditions, but although the actual head/capacity curve differs considerably from the ideal, it still retains the inherent characteristics shown above.

Model tests play an important part in the design of turbo-compressors. Performance curves obtained experimentally from either single- or multi-stage model tests can, with the use of non-dimensional coefficients, be used to forecast the performance characteristics of a full-size machine. Given geometrical similarity and provided that the Reynolds number and Mach number remain unaltered, these characteristic curves are also applicable to machines handling gases of widely differing densities and viscosities under operating conditions of varying initial temperature and pressure.

In both axial-flow and centrifugal compressors there are three components which mainly influence the flow conditions in each stage; (*a*) the guide means, (*b*) the runner, (*c*) the diffuser. The stationary parts, i.e. (*a*) and (*c*), may be provided with vanes. The guide means conduct the gas to the runner in such a way that the entry is made without shock and the most favourable flow conditions are produced at the inlet. The diffuser after the runner serves to convert as much as possible of the kinetic energy of the gas into pressure.

The total energy of the gas at the impeller outlet appears as both static and velocity head as shown in equation (4). The ratio of these two factors varies according to the outlet angle of the impeller vanes β as can be seen from Fig. 3. It is an advantage therefore to have a large part of the total head developed in the impeller where velocities are relatively low and where the conversion of energy into pressure can be done most efficiently. It is for this reason that the majority of manufacturers of multi-stage centrifugal compressors use an impeller with backward-curved vanes.

There are three types of diffusers: (*a*) the annular diffuser which is a ring-shaped space, (*b*) the vaned diffuser consisting of a number of relatively short expanding passages, and (*c*) the volute or scroll-type

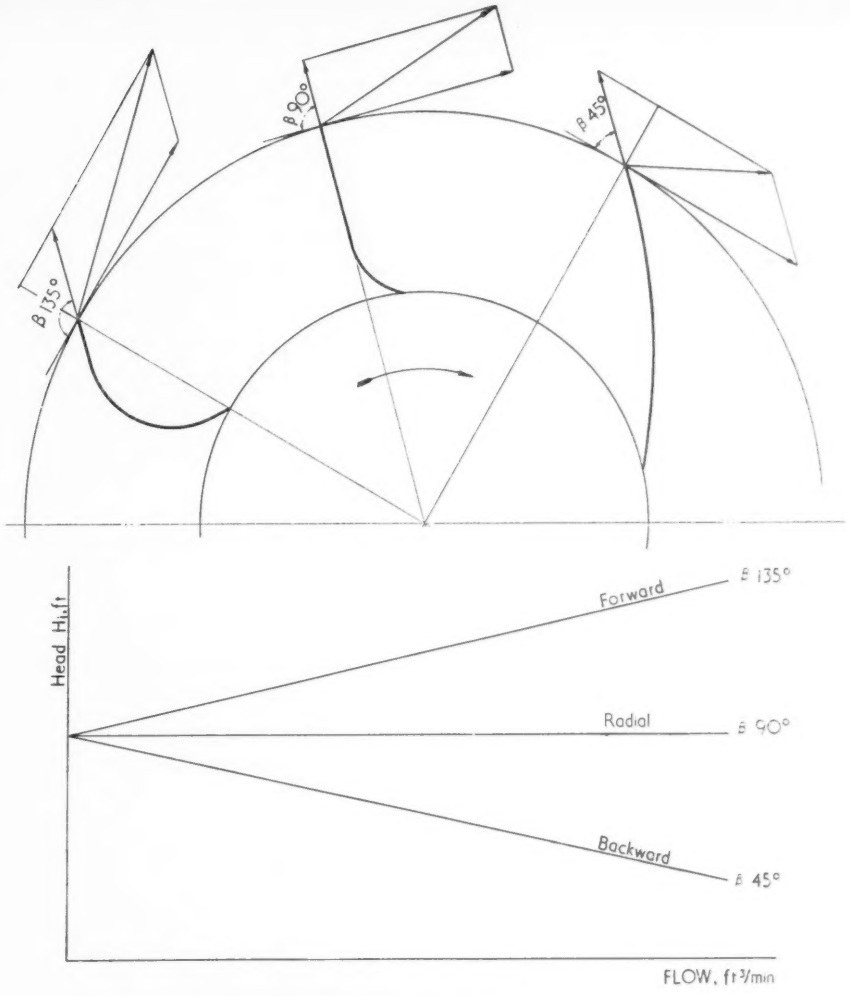


Fig. 3—Theoretical head/capacity curves and outlet velocity diagrams for various vane angles

diffuser which is a spiral shaped passage with increasing cross-sectional area. The diffuser system, where the fluid has ceased to receive any energy, requires the utmost care in design to minimize loss, and for maximum stage efficiency the impeller and diffuser should be so designed that the maxima of their efficiency curves coincide.[3] Each impeller should be co-ordinated with a diffuser adjusted to the flow volume and the pressure ratio.

There is a minimum capacity for each blower at every speed below which the blower operation becomes unstable. This instability is accompanied by a characteristic noise known as 'pumping'. The pumping limit is determined largely by the impeller discharge angle and the type and efficiency of the diffuser fitted. The primary cause of this behaviour lies in the shape of the pressure/volume curve which, after reaching a maximum pressure, begins to fall away towards the zero volume point. When the volume is reduced below the 'surge' or pumping limit, the pressure in the discharge main exceeds that produced by the blower and the flow tends momentarily to reverse. However, as soon as the flow is further reduced the pressure drops in the discharge main and the blower begins to discharge into the pipe again. Such pulsations in pressure and capacity are magnified by the response of the compressible gas in the discharge system.

For a vaned diffuser the resulting stage curves yield a maximum value for efficiency but at the same time the vertex (or surge point) of the pressure/volume curve lies near the optimum operating point. For a vaneless diffuser a continuously rising pressure-curve can be obtained covering a wide volume range but a slightly reduced stage efficiency is unavoidable.

The scroll type of diffuser has, in recent years,

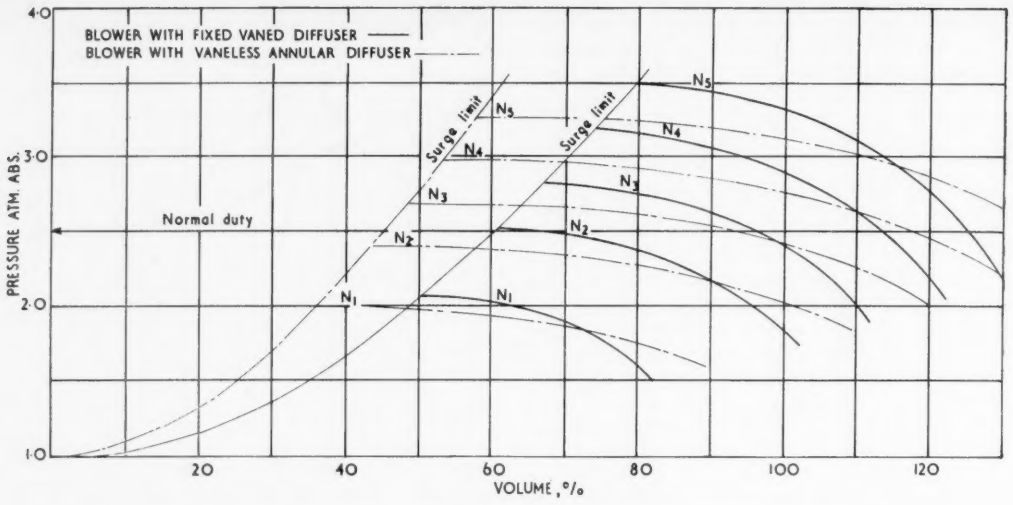


Fig. 4—Pressure/volume characteristics at various speeds, blowers as specified

been developed by both Whittle[4] and Oerlikon.[5] By splitting up the scroll at the impeller periphery into a number of partial scrolls, improved diffuser efficiences have been claimed. Several part-spirals arranged around the circumference, however, involve machining difficulties and consequently an increase in manufacturing costs.

Figure 4 shows the pressure/volume characteristics at various corresponding speeds for two similar machines, both supplied to the same company. The full lines are for a blower with fixed diffuser vanes whilst the dotted lines are for a similar blower supplied with vaneless annular diffusers.

Regulation

The characteristic curve of a turbo-blower is a curve of head, pressure-rise, or discharge pressure plotted against the flow in cubic feet of gas at specified conditions. In addition to this curve it is customary to plot curves of overall efficiency and brake horse-power against flow.

Variation of head capacity requirements may be caused by a variation of the demand for gas at constant pressure, or a constant amount of gas may be required at a variable pressure because of increased resistance to the flow, e.g. as happens with blast-furnaces. On the other hand, variable quantities of gas at different pressures may be required by the process, as is typical for the steel production process. Variation of the blower output to meet the head capacity demand of the system requires special controls to regulate the volume, pressure, or both. These controls operate on several different principles depending on the type of blower, driver, and application.

The alternative methods of regulation of a blower are best seen with the aid of the following relation:

From Euler's equation

$$H_i = (1/g)\,(U_2V_{t_2} - U_1V_{t_1}) \quad \ldots\ldots\ldots\ldots (3)$$

The increase in pressure $P_2 - P_1 = \rho H_i - \Delta p$ where ρ is the average density during compression and Δp is the deficiency of pressure recovery in the diffuser. Combining these, the absolute delivery pressure is given by

$$P_2 = (\rho/g)\,(U_2V_{t_2} - U_1V_{t_1}) + P_1 - \Delta p$$

The delivery pressure P_2 can therefore be affected by

(i) *Speed control*, varying U
(ii) *Inlet throttling*, varying P_1 and at the same reducing ρ
(iii) *Adjustable diffuser vanes*, varying Δp
(iv) *Inlet guide vanes*, varying V_{t_1} by giving the gas a certain amount of pre-rotation before entering the impeller.

Speed Control

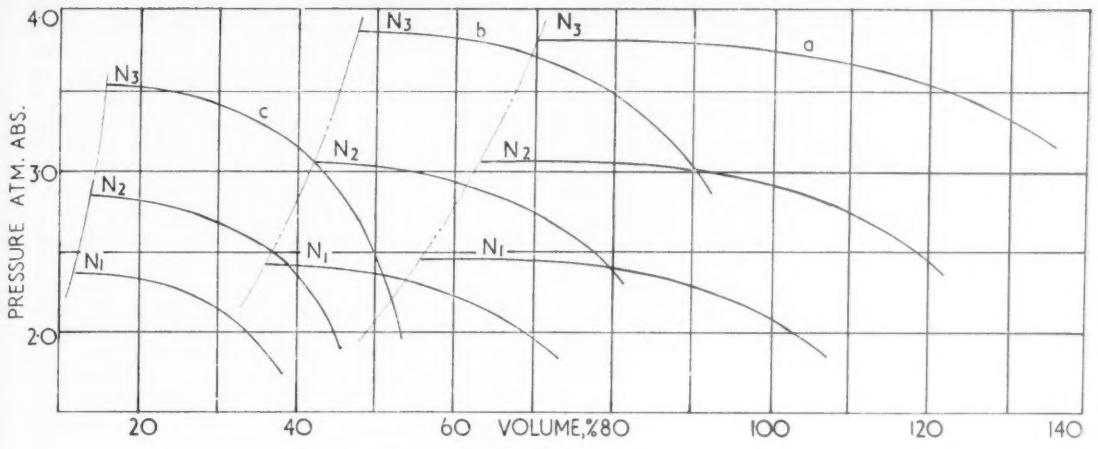
When a blower is driven by a variable-speed driver such as a steam or gas turbine, its speed can be controlled by influencing the turbine governor, and a series of pressure/volume curves obtained covering a wide range of volume and pressure. Therefore it is simple with this method of regulation to obtain constant pressure or constant volume according to requirements. Speed variation of turbine-driven blowers is the most practical and economical way to control capacity. Speed variation of motor-driven units is rarely used because of the electrical losses involved.

Inlet Throttling

This is the simplest and most practical way to vary the rate of flow of a blower driven by a constant-speed motor. For a given speed of rotation, suction throttling does not alter the impeller velocity triangles, hence the delivery head remains constant for any given point on the P/V curves. From the basic thermodynamic law for steady flow compression:

$$H = RT_1 \frac{n}{n-1}\left\{\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} - 1\right\} \text{ft} \quad \ldots\ldots\ldots\ldots (5)$$

It follows that since R is the gas constant, and the



a = diffuser vanes fully open
b = diffuser vanes half-open
c = diffuser vanes quarter-open

Fig. 5—Pressure/volume characteristics of blower with movable diffuser vanes

variation in the inlet temperature T_1 is negligible, and n the polytropic exponent remains unchanged because of constant efficiency, then the pressure ratio P_2/P_1 must remain unaltered. Therefore the blower pressure varies proportionally to the absolute suction pressure. As mentioned above, the impeller velocity triangles remain unaltered, therefore the suction volume referred to the pressure P_1 does not change and the weight of gas inhaled must decrease proportionately to the absolute suction pressure. The power taken by the blower with inlet throttling control is therefore proportional to the suction pressure P_1, since for a particular point on the P/V curve the only change in work done by the impeller is in the weight of gas dealt with.

Adjustable Diffuser Vanes

With a vaned diffuser, for a given impeller speed there is only one capacity at which the diffuser inlet area and vane angle will give the best efficiency. With a volume smaller than the optimum, the diffuser-opening is too large and the efficiency of the diffuser is reduced. If, however, the vane angle and the cross-section of the diffuser channel are reduced by moving the vanes to suit the smaller volume flow, the efficiency increases, which with a constant driving power results in an increase in outlet pressure. Movable diffuser vanes, with each vane pivoted and all vanes moving in unison, may be arranged to vary the inlet area and vane angle to suit the required flow rate. The vane position is usually adjusted manually, but automatic operation has been used with some installations. Figure 5 shows P/V curves at the same speeds for three positions of the diffuser vanes. This device may only be used with gases which are not gummy, corrosive, or erosive, and since the atmosphere in blast-furnace plants often contains a large amount of dust, it is essential that air-filters be provided at the blower intake to protect the vane adjusting mechanism.

Inlet Guide Vanes

If the gas enters the impeller radially then the term U_1V_{t1} in equation (3) is zero. If by means of vanes before the impeller eye a certain amount of rotation is given to the gas at entry, V_{t1} assumes either a positive or negative value depending upon the direction of rotation imparted to the gas, and provides a means for influencing the delivery head. Although the primary role of these guide vanes is to provide pre-rotation ahead of each impeller and thus reduce the head/capacity, the same vanes also act as a throttle to reduce the flow-rate by reducing the gas density at the same time. Variation of the flow is accompanied by a drop in efficiency and even in a neutral position the inlet vanes cause a loss at the impeller approach. The vane-adjusting mechanism must be protected and as with the adjustable vane diffuser, cannot be used with corrosive or erosive gases.

Reduction of head/capacity by this means is always accompanied by a reduction in efficiency, thus indicating that a reduction of the output results primarily from the throttling effect of the guide vanes. The method has little advantage over inlet throttling.

TURBO-BLOWERS IN BLAST-FURNACE PLANTS

The weight of air supplied to a blast-furnace for the production of pig iron exceeds the weight of the solid materials used, being of the order of 4 tons of air per ton of pig iron produced.[6] A 1000-ton furnace, that is, a furnace producing 1000 tons of iron in 24 h, would require about $(4 \times 1000 \times 2240)/(24 \times 60) = 6220$ lb of air per minute which is equivalent to 81,500 ft³/min at normal atmospheric conditions.

When new steelworks are being built or old ones extended, only turbo-blowers are now considered for the blast air. Modern turbo-blowers driven by steam turbines attain practically the same thermal effi-

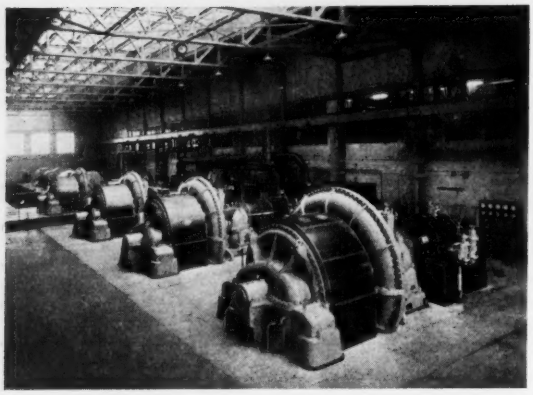


Fig. 6—Four blast-furnace turbo-blowers each to deliver 55,000 ft³/min to 18–30 lb/in² gauge, installed at Consett Iron Co., Ltd.

ciency as reciprocating gas-engine-driven blowers and furthermore they can be built without any technical difficulties for the large air capacities required for modern blast-furnaces.

The main features of the blast-furnace process, which consists fundamentally of a heat exchange between a descending column of solid materials and a column of swiftly ascending hot gases, insofar as it affects the blower, will be described first. The liquified products, molten iron and molten slag, pass out of the furnace at the bottom intermittently and the gasified products pass out at the top continuously.

The hot blast enters the furnace from the hot blast stoves through a pipe encircling the furnace connected to a number of tuyeres regularly spaced around the hearth-well. The molten iron and the molten slag pass down through the combustion zones in front of the tuyeres and into the hearth of the furnace where the iron is collected with the slag floating above it. The slag is allowed to accumulate in the hearth until it nearly reaches the tuyeres and is then drawn off at intervals between casts through the slag notch.

In the lowest part of the hearth-well is the iron notch, or tap hole, through which, at intervals of about 4–6 h, the iron is tapped off until the level inside the furnace is down to a point where the blast begins to blow out the hot gases. When tapping is completed the iron notch is closed by filling up with stopping-clay by means of an electrically-operated iron-notch gun, which enables production to be maintained with undiminished blast quantity even during tapping periods.

The pressure to which the blast has to be compressed depends upon the size and the profile of the blast-furnace, the properties of the iron-ore to be smelted, the degree of sintering, the coke used, etc. and may vary between 10 and 30 lb/in² gauge.

An innovation which has been tried out in a number of furnaces is to operate with a high top-pressure. This method of blowing originated in the U.S.A. but it has also been tried in this country.[7] The technique consists in increasing the pressure at the top of the furnace to 10 or 12 lb/in² which requires a higher than normal pressure at the furnace tuyeres. This makes it possible to introduce more air, which permits burning more coke and hence smelting more iron ore. American blast-furnace engineers claim that the main advantages are a 10% increase in output, less dust carried away by the waste gas, and more uniform operation of the furnace. Though the majority of enquiries received for blowing-plant both for this country and abroad, cover for high top-pressure working, sufficient operating results are not available to enable a definite opinion to be expressed about the future development of this process.

Figure 6 shows the power house of a modern ironworks. Four turbo-blowers each to deliver 55,000 ft³/min of free air at a pressure of 18–30 lb/in², and two 15-MW turbo-generators are shown. Also installed in the same house, but not shown in the photograph, are a turbo blower for supplying air to a Bessemer converter and a 15-MW turbo-generator.*

OPERATING CONDITIONS

The relationship between blast volume and pressure is determined neither by the blower nor by the furnace operator but by the blast-furnace itself. Blast-furnace operators therefore demand a blower which will operate efficiently not only under normal conditions but also over a wide range of working to suit the variable operating conditions of the furnace.

The blower has to force the blast through the mains connecting the blower house and the furnace, and through the stoves, tuyeres, and furnace charge. The resistance to the passage of the air through all these elements is a pure flow-resistance which increases as the square of the air volume, thus the back-pressure curve of the system is a parabola with its vertex at the origin.

Present-day practice is for each furnace to have its own blowing unit. Figure 7 shows the relationship between pressures and flow rates for speeds n_1, n_2, and n_3. It is imperative that the flow-rate through the blower should always be above the minimum volume curve XX, the so-called surge limit, which is established for a given blower by computation and verified by tests. Volumes in the unstable region to the left of this line can only be delivered by using special regulation devices. The system resistance characteristic under normal conditions is shown by curve (1), with the normal operating duty at point N (pressure P_N—volume V_N). If, through a hanging charge, the furnace resistance increases as represented by curve (2), then with a constant blower-speed the new working point would be at O with the flow volume reduced to V_O. To maintain the iron output constant, a constant weight of oxygen is required, i.e. a constant blast volume V_N, which means the blower speed must be increased to the point R. The blower should therefore be provided with a regulator which will vary the speed to maintain a constant intake volume. Due to certain special properties of the iron ore to be smelted, provision is sometimes made for a limiting or constant-pressure device to override the volume regulator when a predetermined maximum pressure

* Plant detailed was supplied by C. A. Parsons and Co., Ltd. to the Consett Iron Co., Ltd., Consett.

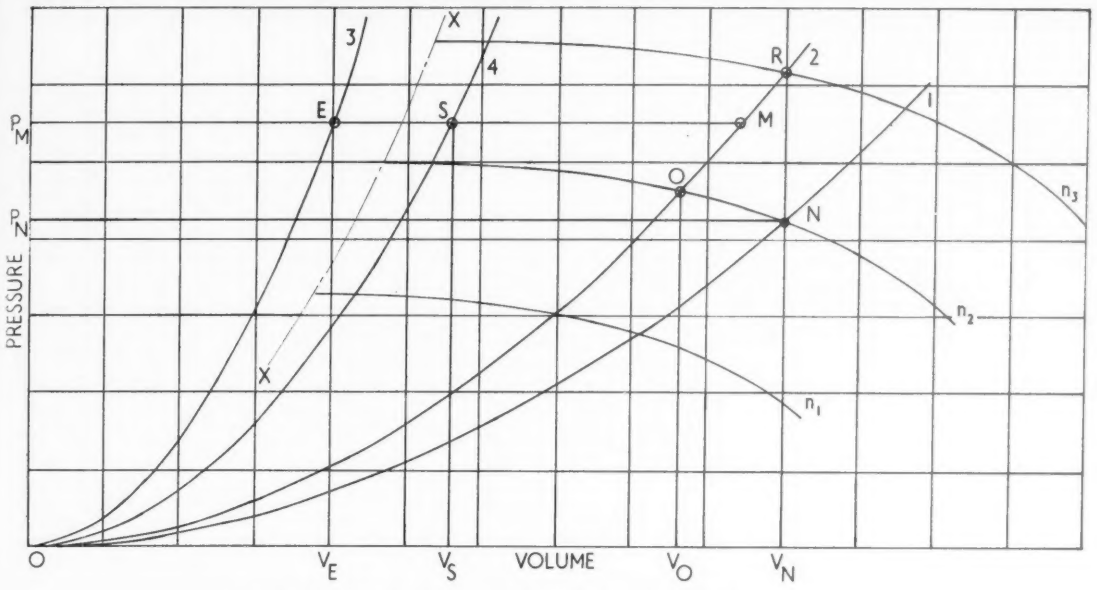


Fig. 7—Pressure/volume relationship for blast-furnace blowing

M has been reached. This regulator comes into operation and controls the blower so as to maintain a constant pressure along the line P_M.

To obtain stable operation of the blower at a working point E outside the limit of stable working, the machine is allowed to deliver a volume V_S with the difference $V_S—V_E$ being discharged to atmosphere through an anti-surge valve. As the blower operates at variable speed the surging volume alters according to the pressure, following approximately a quadratic characteristic. The anti-surge valve, which is under control of both the intake volume and the outlet pressure, is therefore adjusted to commence to open anywhere along the line (4) which is just to the right of the surge limit.

Figure 8 shows diagrammatically Parsons control gear for a blower driven by a steam turbine, which enables all the above controls to be fulfilled. The regulators are of the Askania hydraulic impulse type with oil supplied from the turbine oil system, and control of both volume and pressure is carried out by varying the speed of the turbine. Provision is also made to prevent the machine surging by blowing off sufficient air to ensure that the delivery volume of the blower is always above the surging limit. The constant-volume and constant-pressure regulators operate small control cylinders incorporated in the turbine governor gear. The anti-surge regulator operates a butterfly type blow-off valve in a pipe which branches off the cold blast main.

Constant Volume

A differential pressure which is dependent on the volume of air passing is obtained by suitable connections in the inlet branch of the blower, and controls a sensitive diaphragm in the regulator. This diaphragm in turn moves an oil-jet pipe in such a manner that the jet from the pipe increases or reduces as required, the oil pressure actuating the control cylinder incorporated in the servomotor system which controls the speed of the turbine. The resistance of the diaphragm may be varied by means of a hand adjustment which is provided so that the regulator may be set to operate at any desired volume in the working range. To avoid overstressing the materials used in construction, the blower must be limited to a maximum permissible running speed. It is therefore arranged that when the blower is under the control of the constant-volume regulator, the turbine governor is set for this maximum speed and thus acts only as a limit regulator.

Constant Pressure (or Limiting-Pressure Device)

The constant-pressure regulator is similar in all respects to the constant-volume regulator except that the impulse system is of the bellows-type instead of the diaphragm-type. The force due to the outlet pressure acting on this bellows is balanced by a spring which determines the pressure for which the jet pipe is in the mid-position. For normal operation with the machine under the control of the constant-volume regulator, the adjustment will be set to some predetermined limiting pressure, and the force due to the spring will be sufficient to overcome the force due to the bellows impulse system. The jet pipe will therefore be held over to one side and the piston of the control cylinder in the servo system of the turbine speed control gear held in the out of contact position. Should the resistance of the furnace increase and reach the limiting pressure, the jet pipe moves over to its mid-position and control of the turbine speed is taken over by the pressure-regulator.

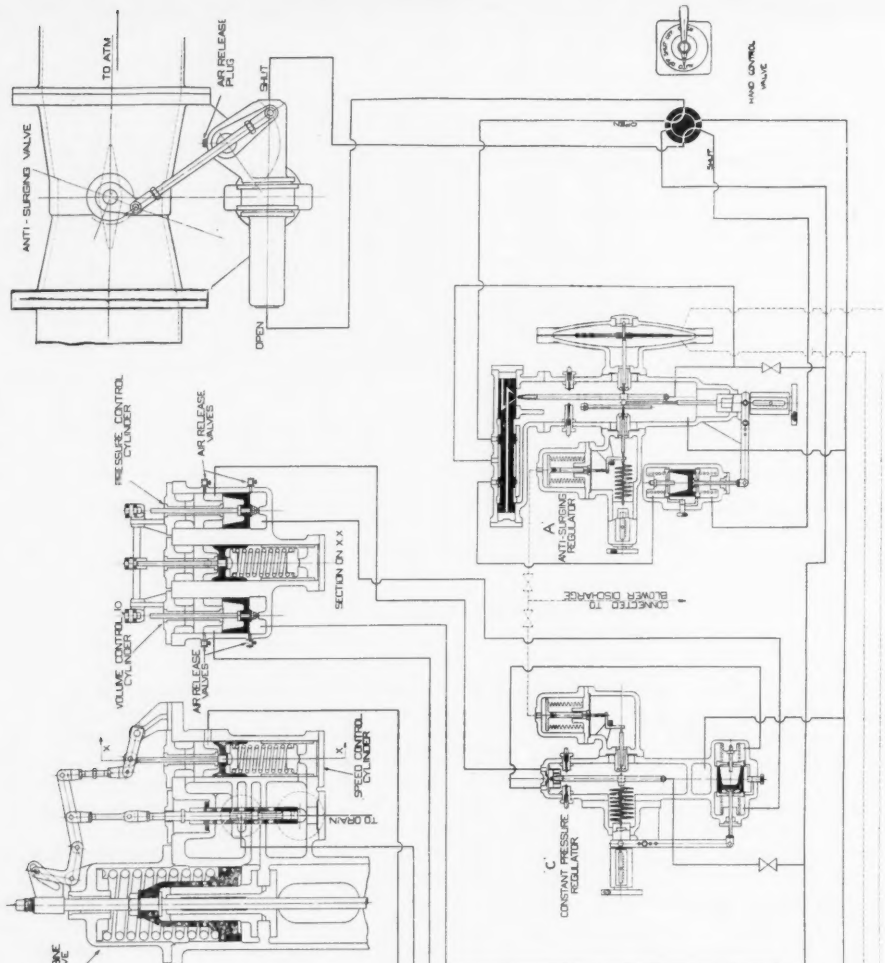


Fig. 8—Diagrammatic arrangement of Parsons turbine control gear with Askania regulators for blast-furnace blowers

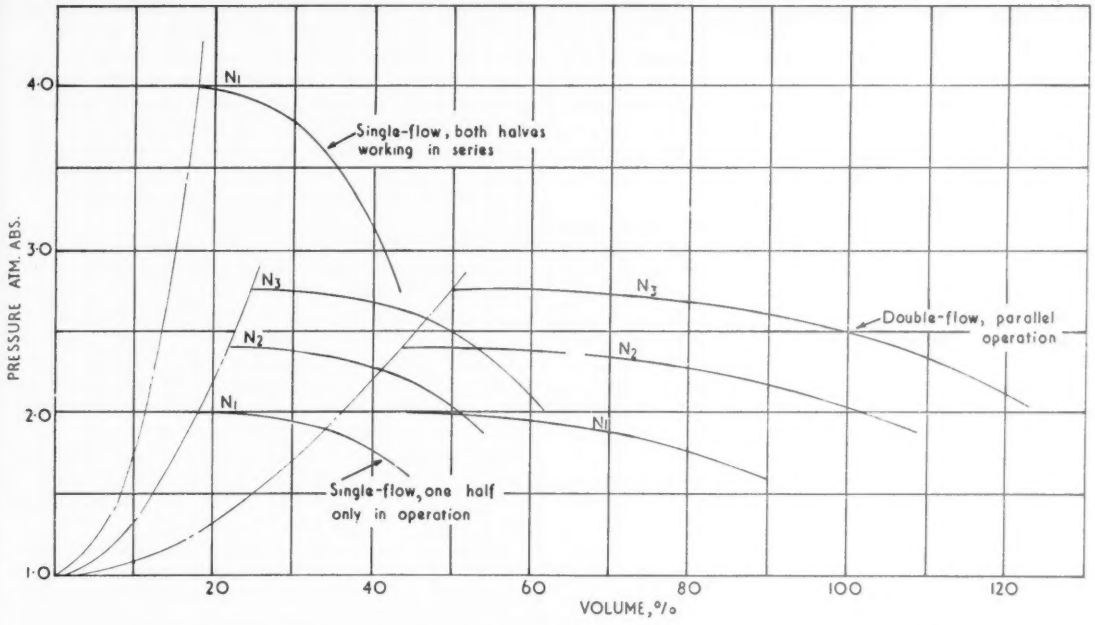


Fig. 9—Pressure/volume characteristics of double-flow blower for special applications

As the furnace resistance eases and the volume flow increases, the control of the machine is automatically transferred from the constant-pressure regulator back to the constant-volume regulator.

Anti-surging segulator

The regulator consists of a sensitive diaphragm which is under the influence of a differential pressure dependent on the volume of air passing through the blower intake, and a bellows-type impulse system which is connected to the blower discharge. The forces exerted by the diaphragm and the bellows are opposed to one another and transmitted by push rods and lever gear to the oil jet pipe. The regulator is therefore only in equilibrium when these forces are balanced. The jet pipe of the regulator operates the blow-off valve through a control cylinder and adjustments are provided whereby the blow-off valve can be set to open along a parabolic curve parallel to and slightly to the right of the limit of stable working of the blower (Fig. 6). During periods when the blower is working normally, i.e. at a volume above the surging limit at any given pressure, the differential pressure on the diaphragm overcomes the force due to the bellows, and the jet pipe is held in a position which keeps the blow-off valve closed.

A hand-control valve is also provided by means of which the blow-off valve may be opened or closed or set in any given position during periods when the automatic regulator is out of commission or when first starting up the machine.

Double-flow Blowers

The modern system, whereby each furnace is provided with an individual blowing unit proportioned to suit the requirements of that furnace, has the disadvantage of requiring a large number of reserve units if the furnaces have capacities which are not equal.

A double-flow blower provided with special valves on the inlet and discharge branches which permit cutting off one half of the unit when capacity approaches the pumping limit of the whole unit, may be adapted as a standby machine to cover the blast requirements of a number of various sized furnaces. By operating in this manner the pumping limit is reduced to half that of the complete unit or, in other words, the blower can operate down to about 25% of its rated capacity. Double-flow blowers may also be arranged for parallel series operation and used with both halves working in parallel to blow a blast furnace, and alternatively with the halves working in series to supply air to a Bessemer converter. Figure 9 shows the characteristics of double-flow blowers for special applications.

'Split-wind' Blowing

A term recently used in connection with the air supply to blast-furnaces is 'split-wind' blowing which may be defined as the 'delivery of wind simultaneously to two or more furnaces from a common main' or, as in the case of an installation now being manufactured, ' the delivery of wind to two or more mains to boost the blast to furnaces each already supplied by a blowing unit.'

This method of operation is not new. Split-wind or collective blowing was fairly common in the past, and a number of ironworks used a common blast main to blow two or more furnaces but the quantity of air delivered to each furnace could only be roughly

controlled. Control of pressure to the furnace was effected by the setting of the cold-blast valve or, in some cases, by means of a furnace valve located in the hot-blast main adjacent to the inlet to the furnace bustle pipe. If the furnaces were of different sizes and if one furnace went on pressure or one was on check, the pressure difference between the required blast and that actually received by the furnaces varied considerably.

Occasionally a furnace plant will temporarily get out of balance necessitating some type of controlled split-wind blowing. The Appleby-Frodingham Steel Company found that with a modified charging technique it was possible considerably to increase output from their existing furnaces but that the limiting factor was the blast available. This shortage of blowing capacity was going to be further accentuated as furnaces became available for relining and modifying with increased hearth diameters. As the replacement of blowing plant was out of the question, the only alternative was some form of split-wind blowing. An order was placed with the authors' firm for the supply of a large turbo-blower capable of delivering 160,000 ft^3/min of air at normal atmospheric conditions against a pressure of 35 lb/in^2 gauge. The blower was to be arranged to supply air to four separate furnace mains individually supplied by four existing turbo-blowers. It was emphasized that there was to be positive control of the air to each furnace under any possible combination of operating conditions, and that the installation was to be safe and generally foolproof. A schematic sketch of the split-wind control is shown in Fig. 10 and indicates the principal parts of the installation.

The blower is of the centrifugal type with a measuring Venturi in the intake and the air discharge is through a non-return valve to a header main which is connected through motor-operated sluice valves to each individual main. Each main also includes a flow orifice, impulse pipes, and a flow-control butterfly valve. In split-wind blowing the header-main pressure will be operated at a minimum differential above the furnace with the highest operating pressure, and the speed of the turbo-blower will be governed by a regulator to maintain this pressure constant. Conventional Askania volume regulators with impulse connections taken from the flow orifices in the cold blast mains will be used to control the butterfly valves in each separate furnace main by means of hydraulic crank-type cylinders. The regulators will be equipped with volume-setting adjustment capable of manual operation at the regulators or push-button operation from the control panels of the existing blowers. Provision is also made for manually-operated hydraulic adjustment of the butterfly control valves should the volume regulators be out of commission. Flow, as measured by each orifice and corrected to standard conditions, and the pressure in each main are recorded and indicated on a panel adjacent to the booster blower. Arrangements are also made whereby the increased flow to any line is indicated on the panel of the existing blower also feeding into that particular line, together with the total air flow to the furnace. For normal operation the booster blower will deliver its full rated volume distributed over the four furnace mains so that in conjunction with the existing machines it will be possible to deliver the maximum volume required to any furnace. All adjustments to flow rates and pressures will be made on the individual units feeding each furnace, with the booster blower working as a base-load machine. This equipment is scheduled to be installed and ready for operation before the end of 1956. Figure 11 shows the above blower during erection in the works.

Axial-flow Blowers

Until recently, only the radial-flow blower has been considered for the production of blast-furnace air but the gas turbine has now directed attention to the axial-flow blower with its 5–7% increase in efficiency at its optimum working point. It would appear, therefore, that with the powers involved for modern blowing units a considerable saving of fuel could be achieved with this type of unit.

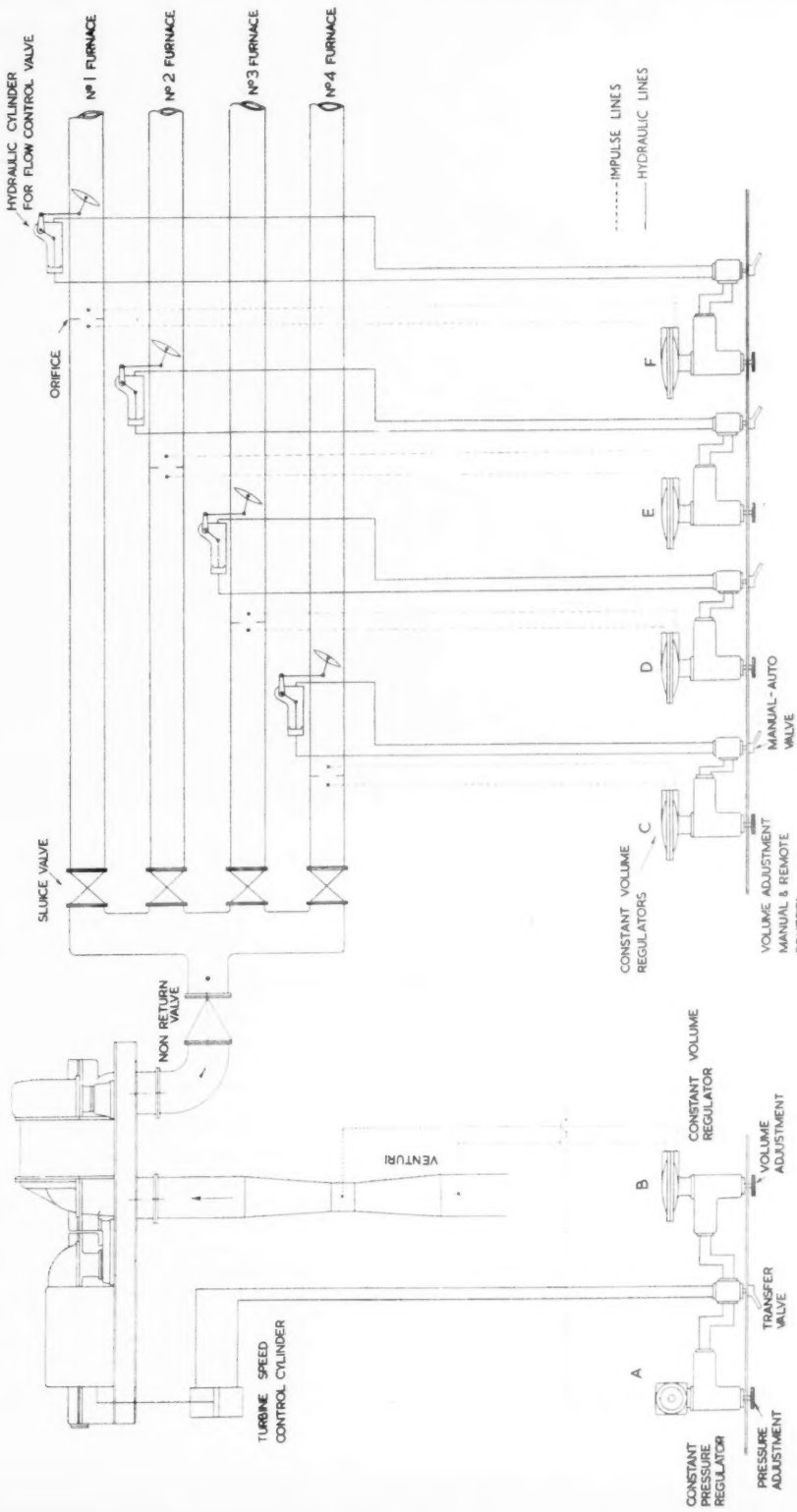
The authors know of only one modern axial-flow blower in use in the U.K. for blast-furnace blowing but a number have been installed in western Europe and appear to be giving satisfactory results.

Figure 12 shows an axial-flow compressor during erection in the works. This compressor is part of a 10,000-kW gas turbine unit and delivers 160,000 ft^3/min of air at normal atmospheric conditions against a pressure of 25-lb/in^2 gauge.

The first requirement in a blower serving a blast-furnace is that of absolute reliability, and in spite of the high efficiency attained by the axial-flow blower, the doubts in the minds of furnace operators regarding the suitability and reliability of the precise aerofoil-form blading used in this type of machine have proved a serious obstacle to their introduction into the iron and steel industry. The blades of an axial-flow blower designed to satisfy aerodynamic requirements are prone to mechanical vibration, and in the past, periodic excitations have been known to cause a fatigue fracture in a blade after a certain period of operation. To overcome this difficulty the blade sections of blast-furnace blowers are considerably increased and with only a slight drop in stage efficiency the demands of sturdiness and reliability in service have been fulfilled.

When the air to be handled contains comparatively large quantities of dust and other foreign matter, dust particles may lead to fouling and erosion of the blades which in time could modify the shape of the blade sections and consequently impair their efficiency. However, with an efficient air filter in the blower suction, fouling and erosion can be practically eliminated.

A disadvantage of the axial-flow blower when compared with the centrifugal type is the steep pressure/volume characteristic and consequent very narrow stable working range. The efficiency also falls off considerably with a flow-volume slightly less or greater than the optimum flow for a specific speed of rotation. Although an axial-flow blower is particularly suitable where large quantities of air have to be delivered, until conditions are such that it is possible to obtain uniform operation of the blast-furnace each case should be examined individually to see which type gives more favourable operating



For blowing one furnace, regulator *B* operates alone
For blowing two or more furnaces in conjunction with other blowing units, regulators *A*, *C*, *D*, *E*, and *F* operate

Fig. 10—Schematic arrangement of controls for split-wind blowing

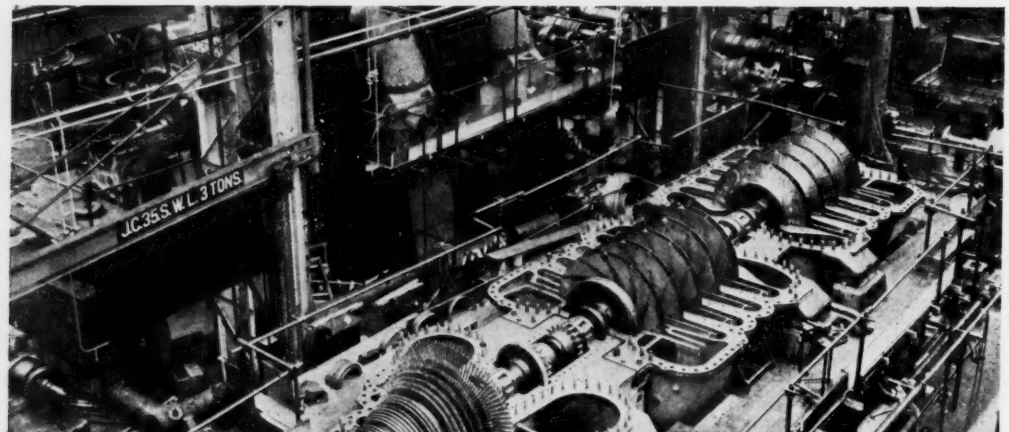


Fig. 11—Turbo-blower in course of erection at Heaton works

conditions over the entire working range. Figure 13 shows comparative pressure/volume characteristics for both axial-flow and centrifugal designs for the same normal operating point.

Gas-turbine-driven Blowers

Blast-furnace or coke-oven gas or a mixture of these gases is ideally suited as fuel for gas turbines. Conditions would therefore appear quite favourable for their use as prime movers to meet the power and blowing requirements in iron and steelworks. Although much thought has been devoted to the application of the gas turbine to the driving of blast-furnace blowers and a considerable amount has been written on the subject, the number of gas-turbine units actually installed in iron and steelworks is extremely small.

Little gain in efficiency can be expected from the straight gas-turbine-driven blower without the inclusion of blast heating as an integral part of the gas-turbine cycle,[8] and blast-furnace managers seem reluctant to make a change from their well-tried Cowper stoves. The discussion of the heat exchanger versus the conventional Cowper stove method of blast heating is not within the scope of this paper, but in passing it may be of interest to note that with the modern nuclear power stations now coming into operation some useful information may be forthcoming in connection with the performance and reliability of large high-temperature heat exchangers. This may result in some further development on the lines of a combined gas-turbine drive and blast heater for blast-furnace service.

Electrically driven Blast-furnace Blowers

In blast-furnace operation the best and most efficient method of delivering varying quantities of air at pressures which also vary considerably is by means of speed regulation of the blower, and as it is not an easy matter to obtain by simple means an economical regulation of the speed with motor drive, electrically-driven blast-furnace blowers are seldom used. A further disadvantage is that the designed operating speed of the blower is almost invariably higher than that for which the motor can be built, and necessitates the inclusion in the drive of a speed-increasing gear. However, it may be an advantage to consider a drive by an electric motor in the case of a standby blower which would rarely be in service and where low initial cost is of more importance than high efficiency. Under these circumstances, a syn-

chronous induction-motor drive with the blower controlled by inlet throttling to meet the desired blast conditions should be quite adequate.

A new system of speed regulation for electrically-driven blast-furnace blowers[9] has in recent years been tried at the Rotherham Works of the Park Gate Iron and Steel Co., Ltd. It consists of a variable-speed d.c. drive using grid-controlled mercury-arc rectifiers. An Askania constant-volume regulator varies the grid voltage and thus governs the rectifier output voltage. This voltage in turn controls the speed of the motor and thereby automatically maintains the volume of air selected by the operator. It is believed that this is the first time grid-controlled rectifiers in conjunction with Askania regulators have been applied to blast-furnace equipment in this country.

TURBO-BLOWERS IN STEELWORKS

For the production of steel from pig iron, the inclusions silicon, phosphorus, sulphur, carbon, and manganese must be reduced to acceptable proportions. The manufacturing process adopted depends upon available basic material and desired finished product.

The O.H. furnace produces high-quality steels whereas the converter using either the Thomas or Bessemer process is used for the large-scale production of ordinary steels suitable for numerous applications but especially favoured in the manufacture of railroad rails, sections, and sheet metal.

In a converter the undesired constituents are reduced by an oxidizing process, and the quantity of air to be blown through the molten iron is determined by the amount of oxygen required for the almost complete combustion of the inclusions in the charge.

The converter, which is a cylindrical vessel with an open conical top, can be tilted about a horizontal axis for charging and pouring. Blast air supplied by a blower is fed through one of the converter-pivots to a chamber under the converter bottom and then through the charge and leaves via the upper opening. Depending upon the composition of the pig iron, a 25-ton converter would require about 25,000 to 30,000 ft³/min of air at normal atmospheric conditions for a blowing time of 15 to 20 min.

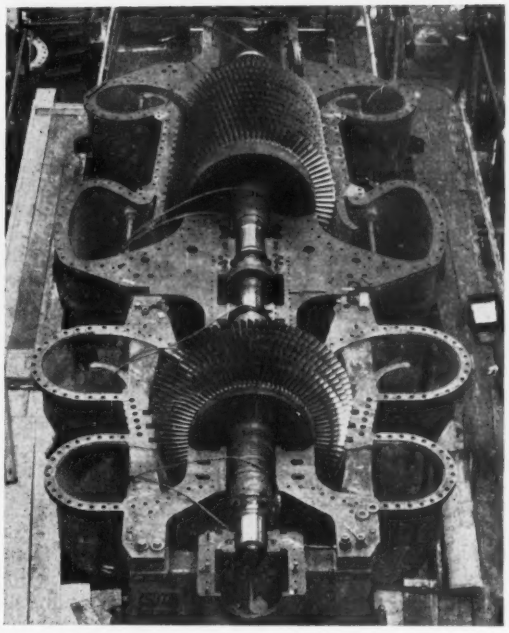


Fig. 12—Axial-flow compressor to deliver 160,000 ft³/min to 25 lb/in² gauge. Compressor is part of 10,000 kW gas-turbine unit, shown here during erection at works

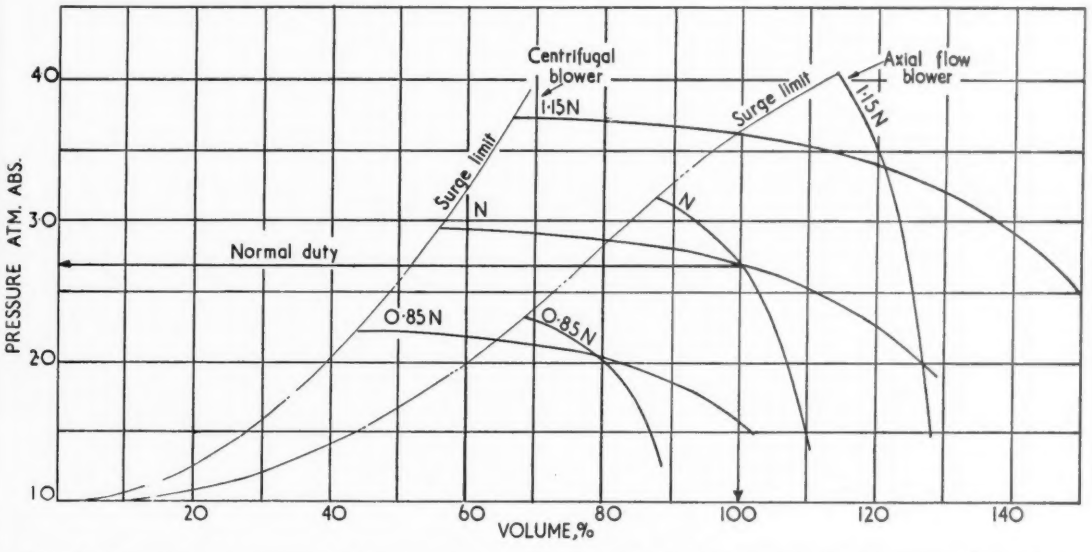


Fig. 13—Comparative pressure/volume characteristics for axial-flow and centrifugal blowers designed for same normal duty

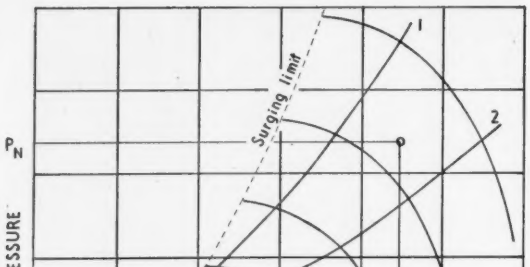
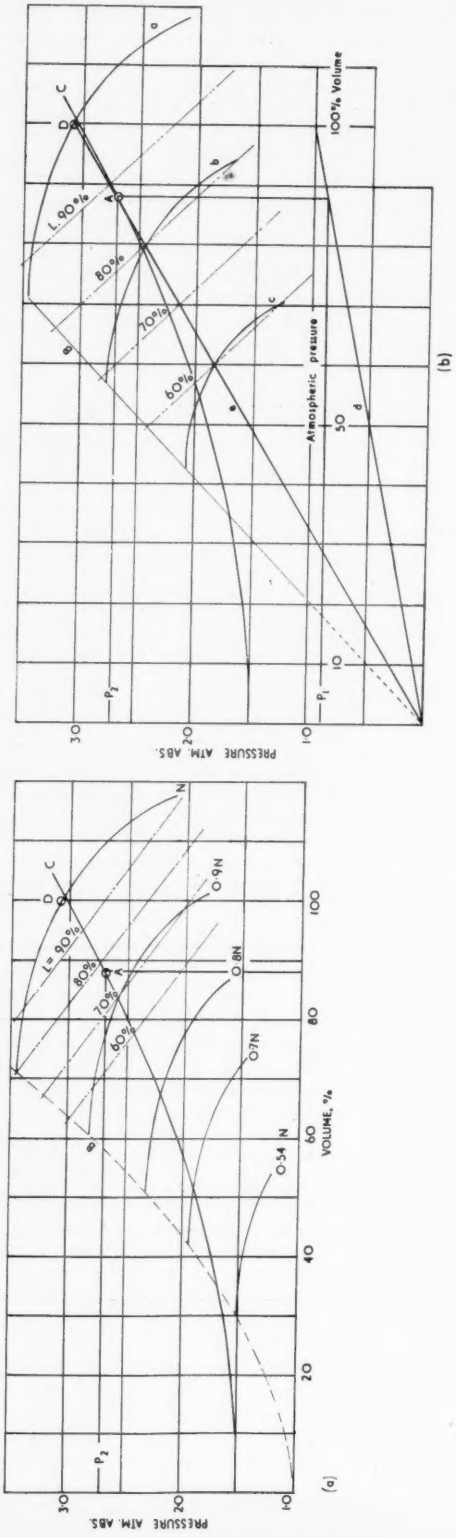


Fig. 14—Pressure- and flow-rates for minimum and maximum resistance of converter

By observing the form and colour of the flame issuing from the converter and adjusting the air volume and pressure to suit the changing conditions throughout the process, an experienced operator can determine to what extent the impurities have been eliminated and the correct time for shutting down the blast. The resistance which the blower has to overcome to force the required quantity of air through the converter is made up by the sum of the resistances of the liquid metal and the flow friction. The static head of the molten iron offers approximately constant resistance to the air and is independent of the air rate. The resistance of the piping between the blower and the converter and the tuyeres in the converter bottom varies as the square of the delivery quantity. The back-pressure curve of the blower is therefore a parabola with its vertex at a height given by the height of the head of liquid.

Figure 14 shows the pressure and air-flow rates for minimum and maximum resistance curves of the converter. Resistance curve (1) applies to a new converter bottom with the tuyeres all of designed diameter, whilst curve (2) is the resistance curve after the converter bottom has become worn and the tuyeres enlarged. The pressure/volume range of the blower for various speeds of rotation is also indicated.

Two basic methods of regulation are employed for steelworks blowers according to whether the speed is constant or variable. Blowers with suction throttling



A = operating point
B = surging limit
C = resistance characteristic of converter
D = design point
L = lines of constant power
P_1 = absolute suction pressure
P_2 = absolute outlet pressure
a = P/V curve without suction throttling
b = P/V curve, absolute suction 0·8 atm
c = P/V curve, absolute suction 0·6 atm
d = line of absolute suction pressure for outlet pressures corresponding to line e
e = line of constant blower efficiency with inlet throttling

Fig. 15—Power consumption for variable speed (turbine drive) and constant speed (motor drive) steelworks blowers

or variable-speed control have similar characteristics; every position of the suction throttle valve (or every speed) is associated with a pressure/volume curve and a definite operating point.

During the blowing period of a charge, the blast requirements fluctuate considerably and both the pressure and quantity of the blast air must be capable of being quickly adapted to the varying conditions. Remote control is therefore normally used to enable the blower to be controlled from the converter platform. The use of remote control has the added advantage of being accompanied by a reduction in engine-room staff, the blowing unit being unattended except for starting and stopping and the occasional checking of the lubrication system.

If steam and cooling water are available, a steam-turbine is usually the most suitable driving unit for a steelworks blower with speed regulation effected by influencing the turbine governor. By means of switches mounted on the control table of the converter platform, a reversible electric motor coupled to the regulating bush of the turbine governor enables the speed of the unit to be varied at will between maximum speed and idling speed. Signal lamps to indicate upper and lower limits of speed, and an airblast pressure gauge are also mounted on the control table.

In the case of an electrically driven blower where speed variation is neither simple nor economical, the cheapest and most practical drive is the synchronous induction motor with the blower pressure/volume controlled by a suction throttling device. The remote control is similar to that of a turbine-driven unit with a reversible electric motor controlled from the converter platform operating the regulating bush of an oil servo-operated throttle valve, and the signal lamps indicating the fully open and closed positions of the valve. Figure 15 shows the power consumption for both variable-speed (turbine drive) and constant-speed (motor drive) blowers.

The operating conditions in different plants vary appreciably and the relative merits of both steam and electrically driven prime movers should be carefully examined over the complete range of operation. It is also advantageous not to choose the blower larger than is necessary so that the operating range shall lie in the region of maximum efficiency and thereby avoid the frequent operation of the blow-off valve, a process which is always associated with losses.

Increased outputs of high-quality steel have been achieved by making use of the 'Duplex' process which consists of removing the carbon, silicon, etc., from the pig iron in converters, but finishing and refining in O.H. furnaces. This practice reduces the work in the O.H. furnace to a minimum and enables much larger outputs per furnace to be obtained. The capital outlay per ton of ingot is as a result considerably less than for a straight O.H. plant.

CONCLUSION

With the ever-increasing demand for steel and the steeply rising cost of fuel, the drive towards increased output and higher efficiency must be intensified. New techniques are being developed, e.g. the use of tonnage oxygen, and new equipment is being installed on a far more extensive scale than at any previous time. To ensure that the full potential benefits of such schemes are achieved, it is necessary for close contact to be maintained between steelworks and blower engineers from the time when new plant is first being considered right through until it has proved itself in service.

References

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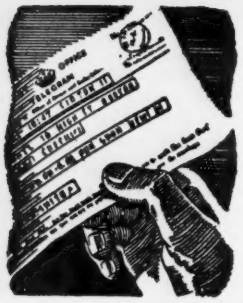

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Autumn General Meeting

The **Autumn General Meeting** of The Iron and Steel Institute will be held at 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 21st and 22nd November, 1956.** Buffet luncheons will be provided in the Library on both days.

The following is the detailed programme:

Wednesday, 21st November, 1956

Morning Session

10.45–11.00 A.M.—Formal business and election of members.

11.00 A.M.–1.00 P.M.—Presentation and joint discussion of:

"*Recording Techniques for Rolling Mill Operation Studies*," by E. A. Chard, W. W. Hastings, and D. F. Nettell (*August*, 1956).

"*The Time Characteristics of the Slabbing Mill*," by H. G. Jones, D. T. Steer, and P. D. Dickerson (*August*, 1956).

"*Note on the Principles Governing the Design of Ingots for High Output in the Slabbing Mill*," by H. G. Jones, P. D. Dickerson, and D. T. Steer (*August*, 1956).

"*Maximum Utilization and Problems of Wide-strip Rolling and Sheet Finishing Equipment*," by H. H. Ascough (*September*, 1956).

1.00–2.15 P.M.—Buffet Luncheon in the Library (tickets 4*s.* 6*d.* each).

Afternoon Session

2.15–3.00 P.M.—Presentation and discussion of:

"*Automatic Stock-level Control on Blast-furnaces*," by I. Kjellman and K. Grönblad (*February*, 1956),

3.00–3.45 P.M.—Presentation and discussion of:

"*The Measurement of Gas Transit Times in a Blast-furnace*," by T. W. Johnson (*September*, 1956).

3.45–4.45 P.M.—Presentation and discussion of:

"*Studies of Blast-furnace Assessment*," by J. M. Ridgion and A. M. Whitehouse (*November*, 1956).

Thursday, 22nd November, 1956

Morning Session

10.00–11.15 A.M.—Presentation and joint discussion of:

"*The Enthalpy and Specific Heat of Iron and Steel. A Critical Survey of the Methods of Determination*," by J. R. Pattison (*August*, 1955).

"*An Analysis of the Available Data on the Total Heat of Commercial Steels*," by J. R. Pattison (*May*, 1956).

"*The Enthalpy of a* 0·12% *Carbon Steel*," by J. R. Pattison and T. H. Lonsdale (*July*, 1956).

"*The Enthalpy of Pure Iron*," by J. R. Pattison and P. W. Willows (*August*, 1956).

11.15–11.45 A.M.—Interval: light refreshment will be served in the Library.

11.45 A.M.–1.00 P.M.—Presentation and discussion of:

"*The Study of* 7% *and* 8% *Chromium Creep-resisting Steels for Use in Steam Power Plant*," by M. G. Gemmill, H. Hughes, J. D. Murray, F. B. Pickering, and K. W. Andrews (*October*, 1956).

1.00–2.15 P.M.—Buffet Luncheon in the Library (tickets 4*s.* 6*d.* each).

Afternoon Session

2.15–4.00 P.M.—Presentation and joint discussion of:

"*The Tempering and Nitriding of Some* 3% *Chromium Steels*," by C. C. Hodgson and H. G. Baron (*March*, 1956).

"*Some Experiments on the Composition of Carbides in Low-alloy Steels*," by J. E. Bowers (*July*, 1956).

"*Bainitic Retained Austenite*," by J. A. Cameron (*July*, 1956).

"*The Temperature of Formation of Martensite and Bainite in Low-alloy Steels. Some Effects of Chemical Composition*," by W. Steven and A. G. Haynes (*August*, 1956).

"*The Tempering of Plain Carbon Steels*," by E. D. Hyam and J. Nutting (*October*, 1956).

"*Alloy Carbides Precipitated during the Fourth Stage of Tempering. An Electron Microscopic Examination*," by K. Kuo (*November*, 1956).

NEWS OF MEMBERS

Mr. **K. T. Bassett** has relinquished his position as Metallurgist with the Fairey Aviation Co., Ltd., Hayes, and has joined the staff of Henry Wiggin and Co., Ltd., Hereford.

Mr. **R. Boler** has been awarded the degree of B.Met. with honours from Sheffield University and has taken up the post of Technical Assistant in the Metallurgical Department of Blackburn and General Aircraft Ltd.

Mr. **P. H. Bowker** has been awarded a B.Sc. in Metallurgy at King's College, University of Durham, and has also taken up an appointment as Metallurgist with the English Electric Co., Ltd., Preston, Lancs.

Mr. **G. T. Brown** has left Linread Ltd., Birmingham, and has joined the staff of the G.K.N. Research Laboratories, Wolverhampton.

Mr. **E. H. Bucknall** has been appointed Visiting Professor of Metallurgical Engineering, University of Texas, Austin, Texas, U.S.A.

Mr. **H. G. W. Debenham** has been appointed Managing Director of Skinningrove Iron Co., Ltd.

Mr. **W. M. Fern** has left Consett Iron Co., Ltd., and has joined the Steel Company of Wales Ltd. as Assistant Melting Shop Manager at the Abbey Works, Port Talbot.

Mr. **B. G. Fisk** has taken up an appointment as Mineral Dressing Engineer with Sukulu Mines Ltd., Tororo, Uganda, British East Africa.

Sir **Charles Goodeve,** F.R.S., has been awarded the honorary degree of Doctor of Science by Sheffield University.

Mr. **P. Kingsley-Jones** has been awarded the degree of B.Sc. in the University of Wales.

Mr. **C. W. Latty** has terminated his commission in the Royal Navy and has taken up an appointment as Metallurgist with the Steel Company of Wales Ltd., Port Talbot.

Mr. **R. Mather,** who has held the combined appointment of Chairman and Managing Director of Skinningrove Iron Co., Ltd., for the past nine years, retired from the office of Managing Director on 30th September. At the request of the Directors, Mr. Mather has agreed to continue as Chairman of the Company.

Mr. **B. J. Meadows** has been awarded the degree of B.Sc. with first-class honours in Engineering (Metallurgy) from London University. He has also been elected an Associate of the College of Technology, Birmingham.

Dr. **Robert Mehl** has been awarded the Henri Le Chatelier Medal of the Société Française de Métallurgie.

Mr. **G. G. Musted** has been appointed West Midland Technical Representative of Courtburn Positioners Ltd.

Mr. **W. J. Neagle-Jones** has left Armstrong Siddeley (Brockworth) Ltd. to take up an appointment with the Steel Company of Wales Ltd., Tinplate Division, Swansea.

Mr. **G. C. Oram,** Manager of the Central Engineering Workshops at Appleby-Frodingham Steel Company, Scunthorpe, has been additionally appointed Technical Consultant, Engineering Works, to the United Steel Companies Ltd.

Mr. **W. D. Parry** has left the Guest Keen Iron and Steel Co., Ltd., Cardiff, to become an Assistant Development Engineer with the Consett Iron Co., Ltd., Consett, County Durham.

Mr. **F. G. Phipps** has been appointed a Director of Davy and United Roll Foundry Ltd.

Mr. **F. Pickworth** has joined the Board of the English Drilling Equipment Company as Chairman.

Mr. **S. V. Radcliffe** has been awarded the degree of Ph.D at the University of Liverpool and has taken up a post as Research Associate in the Department of Metallurgy, Massachusetts Institute of Technology, Cambridge, Massachusetts, U.S.A.

Mr. **J. Savas** has taken up an appointment with Winters Foundry and Machine Co., Inc., Canton, Ohio, U.S.A.

Dr. **P. P. G. L. Siriwardene** has been appointed Lecturer in Metallurgy in the Faculty of Engineering of the University of Ceylon, Colombo. This course in metallurgy is the first to be instituted in Ceylon and a laboratory has been built for metallographic work.

Dr. **P. H. Sykes** has been appointed Chairman of the Board of the newly formed company British Oxygen Research and Development Ltd.

Mr. **R. Tate** has taken up an appointment of Assistant to the Materials and Process Engineer, Trans Canada Airlines, Montreal.

Mr. **H. G. Thomas** has left Norway to rejoin his employers, Davy and United Engineering Co., Ltd., Sheffield.

Mr. **R. N. Wilson** has been awarded the degree of M.Met. at the University of Sheffield and has taken up an appointment as Scientific Officer to the Ministry of Supply at the Royal Aircraft Establishment, Farnborough, Hants.

Mr. **R. Woodward** has left Fairey Aviation Ltd. and has taken up a position as Assistant to the Foundry Manager at the Distington Engineering Co., Ltd., Workington.

Obituary

Dr. **David Binnie** (*elected* 1927), of the Lancashire Steel Corporation Ltd., on 3rd October, 1956.

Mr. **Basil Gray** (*elected* 1943), of the English Steel Corporation Ltd., Sheffield, on 7th October, 1956, at the age of 68.

Mr. **Erle G. Hill** (*elected* 1945), of Wheeling Steel Corporation, Wheeling, West Virginia, U.S.A., in July, 1956.

Mr. **Ernest Kerl** (*elected* 1932), of Pretoria, South Africa, on 21st September, 1956, at the age of 78.

Dr. **Gustaf Alexander Lillieqvist** (*elected* 1946), of East Chicago, Indiana, U.S.A., on 31st May, 1955.

Mr. **Harold Shillitoe,** J.P. (*elected* 1914), Chairman and Founder of British and Continental Traders Ltd., on 7th September, 1956.

Dr. **Theodor Suess** (*elected* 1949), of Düsseldorf, on 4th March, 1956, at the age of 63.

CONTRIBUTORS TO THE JOURNAL

R. Barber, B.Sc.—Head of the Research Department, Land Pyrometers Ltd.

Mr. Barber was born in 1925 and was educated at High Storrs Grammar School, Sheffield, and at Sheffield University. He was an Assistant in the Pyrometry Department of Hadfields Ltd. from 1941 to 1944 and then joined the Physics Department of the B.S.A. Group Research Centre, leaving in 1947 to attend the University. He joined his present organization after graduating in Physics in 1950 and became Head of the Research Department in 1956.

J. G. Hines, Ph.D.—Technical Officer, Imperial Chemical Industries Ltd., Billingham Division.

Dr. Hines was educated at the Simon Langton School, Canterbury, the Royal Grammar School, Worcester, and at Selwyn College, Cambridge. In 1951 he obtained first-class honours in Part II of the Natural Science Tripos (Metallurgy) and began four years of research into the mechanism of stress-corrosion cracking; this research was carried out in the Department of Metallurgy, Cambridge University, under the general supervision of Dr. T. P. Hoar. Dr. Hines was awarded an M.A. in 1955 and a Ph.D. in 1956. He took up his present appointment in 1955 and is concerned with plant-corrosion problems and with long-term research on corrosion.

H. Hughes, B.Sc., Ph.D., A.Inst.P.—Research and Development Department, the United Steel Companies Ltd.

Dr. Hughes was born in 1925 and was educated at Holyhead Grammar School and at the University College of North Wales, Bangor. He graduated with first-class honours in Physics in 1946 and obtained the degree of Ph.D. in 1949 for work on order-disorder in copper–gold alloys. He joined the staff of the United Steel Companies Ltd. in November, 1949, and has worked in the Physics Section. Dr. Hughes is at present in the X-ray Section.

J. D. Murray—Head of the High Temperature Metals Section, Research and Development Department, the United Steel Companies Ltd.

Mr. Murray was born in April, 1926, and was educated at De La Salle College, Sheffield, and at Sheffield University, from which he was awarded an Associateship in Ferrous Metallurgy. He joined the United Steel Companies Ltd. in 1942 as a Junior Assistant in the Metallurgical Section, leaving in 1944 for H.M. Forces. On completing his service he returned to the company in 1948 as a Research Assistant in the High Temperature Metals Section of the Research and Development Department. He became Senior Assistant in 1952 and Head of the Section in 1956. Mr. Murray is an Associate of the Institution of Metallurgists.

R. J. Taylor, B.Sc., F.S.S.—Statistician with the Operational Research Department of the British Iron and Steel Research Association.

Mr. Taylor studied Mathematics and Physics at University College, London, and graduated with honours in 1952. Before taking up his present appointment he was employed by the National Coal Board.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Open Days at Sheffield

Nearly three years have elapsed since B.I.S.R.A.'s Laboratories at Sheffield were opened by H.R.H. The Duke of Edinburgh.

The provision of laboratory and ancillary facilities specifically designed for research gave an added momentum to the work of the local Divisions—Steelmaking, Mechanical Working, and Metallurgy (General).

Progress made since 1953 was displayed to B.I.S.R.A. members at Open Days held on 6th and 7th September, when nearly 600 visitors toured the premises and watched a series of demonstrations.

Among the projects demonstrated by the Steelmaking Division were the continuous casting of steel and studies of the effect of mould dressings on surface quality and of improved design of feeder heads.

Experimental plant on show included the 10-cwt electric arc furnace and a $\frac{1}{2}$-scale model O.H. furnace equipped with a calorimeter hearth.

The Mechanical Working Division, concerned with the processes by which the ingot is made into a finished product, showed numerous applications of the results of research to plant design and operation. These included the application of automatic gauge control to cold strip rolling, developments in wire drawing, and advances in forging practice. The application of remote position control to forging operations was also demonstrated.

The Metallurgy (General) Division illustrated work on fatigue, projects dealing with the effects of impurities on grain boundaries, and the growing complexity and comprehensive character of modern analytical methods.

Other displays illustrated the work of those Divisions of B.I.S.R.A. located in London, South Wales, and the North East coast, and the various services developed by the Association over the past ten years.

DIARY

1st Nov.—Leeds Metallurgical Society—"*Powder Metallurgy applied to Mechanical Parts*," by H. Davies—Large Chemistry Lecture Theatre, The University, Leeds, 7.15 p.m.

6th Nov.—Institution of Engineering Inspection (Coventry Branch)—"*Quality Control and Inspection of Steel Castings*," by R. B. Naylor—Room A5, Coventry Technical College, 7.30 p.m.

6th Nov.—Sheffield Metallurgical Association (Jointly with the Royal Institute of Chemistry)—"*Modern Trends in Metallurgical Analysis*," by W. T. Elwell—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

7th Nov.—Manchester Metallurgical Society—"*The Properties of Hiduminium* 100 (*S.A.P.*)," by Dr. W. M. Doyle—Manchester Room, Central Library, Manchester, 6.30 p.m.

7th Nov.—Newport Metallurgical Society (Jointly with The Iron and Steel Institute)—"*Bessemer and the Bessemer Process*," by J. Mitchell, C.B.E.—Whitehead Iron and Steel Institute, Newport, 7 p.m.

7th–9th Nov.—Verein Deutscher Eisenhüttenleute—*Eisenhüttentag*—Düsseldorf.

8th Nov.—Institute of Metals (Birmingham Section)—"*The Metallurgy of Steel for Deep Drawing and Pressing*," by A. J. K. Honeyman—Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, 6.30 p.m.

13th Nov.—Institution of Engineering Inspection (South-Western Branch)—"*Modern Developments in Ultrasonic Testing*," by J. Brigg—Grand Hotel, Broad Street, Bristol, 7.30 p.m.

13th Nov.—Sheffield Metallurgical Association—"*Some Properties of High Melting Point Metals*," by Dr. L. Northcott—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

15th Nov.—Liverpool Metallurgical Society (Jointly with the Institute of Metals, Liverpool Branch)—"*Some Metallurgical Aspects of Welding Non-ferrous Metals*," by P. T. Houldcroft—Liverpool Engineering Society, The Temple, Dale Street, Liverpool, 7 p.m.

18th–24th Nov.—Société de Chimie Industrielle—*Twenty-ninth Congress*—Maison de la Chimie, 28 rue Saint-Dominique, Paris 7e.

18th–24th Nov.—Fédération Européenne de la Corrosion—*First Congress*—Maison de la Chimie, 28 rue Saint-Dominique, Paris 7e.

19th Nov.—North-East Metallurgical Society—"*Analytical Control by the Quantometer*," by W. S. Sykes—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

20th Nov.—Sheffield Metallurgical Association—"*Some Aspects of Ceramics in Nuclear Energy*," by Dr. P. Murray—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

21st Nov.—Manchester Metallurgical Society—"*The Role of Grain Boundaries in Creep*," by D. McLean—Manchester Room, The Central Library, Manchester, 6.30 p.m.

21st Nov.—Swansea Metallurgical Society—"*Non-destructive Testing of Metallic Structures*," by D. W. Hopkins—Central Library, Swansea, 7 p.m.

21st Nov.—Institute of British Foundrymen—"*Symposium on Dust, Fume, Heat, and Noise Suppression*": (*a*) "*Cupola Furnaces*," by M. M. Hallett; (*b*) "*Electric-arc Steel Furnaces*," by J. Bain; (*c*) "*Crucible Furnaces*," by D. W. Brown—Constitutional Club, Northumberland Avenue, London, W.C.2, 7.30 p.m.

21st–22nd Nov.—The Iron and Steel Institute—*Autumn General Meeting*—4 Grosvenor Gardens, London, S.W.1, 10.45 a.m. (21st); 10 a.m. (22nd).

22nd–23rd Nov.—British Nuclear Energy Conference—Symposium on "*Calder Works Nuclear Power Plant*"—Central Hall, Westminster, London, S.W.1, 10 a.m. each day.

27th Nov.—Sheffield Metallurgical Association—"*Feeding Compounds*," by D. W. Leonard—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield 3, 7 p.m.

TRANSLATION SERVICE

(The previous announcement was made in the September, 1956, issue of the *Journal*, p. 79.)

Translations in Course of Preparation

(Swedish). G. Wallquist and K. Gedin: "The Magnitude of the Mill Spring in Hot Rolling." (*Jernkontorets Ann.*, 1956, vol. 140, pp. 155–187).

(Russian). N. K. Leonidov: "The New Russian 2000 m³ Blast-furnace." (*Stal*, 1956, No. 2, pp. 115–124).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subject

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MINERAL RESOURCES

The Ironsands of New Zealand. (*Times Rev. Indust.*, 1956, **10**, Feb., 80–81). A review is made of the possibility of the development of these ironsands now that tests have shown that electric smelting can be used. Preliminary survey indicates over 700 million tons of iron in the ironsands. The high titania content precludes melting in a conventional blast-furnace. The recovery of titania is also considered.

The formation of Reaction Skarn in Iron Ores of Central Sweden. N. H. Magnusson. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg*, 1952. 1954, 427–430). [In English]. Origins are discussed.

Macedonian Iron Ores. C. Rekar. (*Rudarsko-Metalurški Zbornik*, 1954, No. 1, 27–52). [German Summary]. An account of localities, compositions, methods of concentration, and blast-furnace utilisation is given.

Geology and Mineral Fuels of Parts of Routt and Moffat Counties, Colorado. N. W. Bass, J. B. Eby and M. R. Campbell. (*U.S. Geol. Survey Bull*, 1955, 1027-D).

Chromite. M. S. Krishnan. (*Bulletin of the Geological Survey of India*, 1953, Ser. A, No. 7, pp. 47). Deposits in India are mentioned with a brief account of uses, grades and prices, and a list of World deposits.

Observations on Indonesian Mineral Resources and their Development. E. M. Irving. (*Philippine Geol.*, 1956, **10**, March, 33–51). The occurrences of magnetite-hæmatite and lateritic ores are given.

ORES—MINING AND TREATMENT

Chemical and Metallurgical Properties of Low Grade Complex Iron Ores and Rational Methods of Their Utilisation. D. P. Bogatskii and G. G. Urazov. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (3), 108–121). [In Russian]. Chemical and mineralogical composition of some low grade Russian iron ores containing cobalt and nickel as well as possible methods of extraction of individual metals were studied. On the basis of results obtained methods of utilisation of these ores are discussed.—V. G.

Evaluation of Iron Ore Properties. W. M. Fielder. (*Canad. Min. J.*, 1956, **77**, Apr., 80–82, 101). Evaluation of iron ore properties from the point of view of the blast furnace operator and steel plant manager, transportation, long range planning, development and finance is discussed.—T. E. D.

The Determination of Magnetite in Ores, Based on a Measure of the Intensity of Magnetisation. M. Angeli. (*Doc. Mét.*, 1955, July-Aug.-Sept., 59–70). A method is described for determining the magnetite content of ores by measuring the intensity of magnetisation induced in a sample placed in a strong magnetic field. The effect of particle size on the results is considered and the standardisation of the apparatus is described. Results obtained by this method on seven different ore samples are compared with the results of chemical analysis, the mean difference between the two methods being 1·1%.—B. C. W.

Barytes in Iron Ores. C. Rekar. (*Rev. Mét.*, 1955, **52**, Dec., 965–972). The presence of barytes in Jugoslav ores raises the question of desulphurization. Dissociation temperatures and conditions in presence of other mineral constituents has been studied. The effects of BaO on slag viscosity is also recorded.

Observations on the Treatment of Iron Ore in the U.S.A. P. Emery. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1955, **12**, (12), 2363–2374). Sources of ore used in the U.S. are examined with particular reference to the diminishing supplies of rich ores. Data concerning pilot plants for taconite treatment are tabulated. Crushing and grinding methods are briefly described. Heavy media separation, selective grinding, high and low intensity magnetic separation, magnetic roasting with low intensity magnetic separation, and flotation are outlined. Agglomeration methods are discussed.—T. E. D.

Uses of Vibrational Waves in Metallurgical and Mineral Dressing Processes. J. K. Almond. (*Metal Treatment and Drop Forg.*, 1955, **22**, Nov., 475–480). The author reviews the work done in recent years on the uses of ultrasonic vibrations in industry. He deals with the effects on molten metals, ultrasonic machining, powder production and comminution, and various applications in mineral dressing operations, coagulation and dispersion in liquid and gas phases and boiler treatment. 46 references.—P. M. C.

FUEL—PREPARATION, PROPERTIES, AND USES

Coal, Chemical and Other Process Uses. H. J. Rose and R. A. Glenn. (*Indust. Eng. Chem.*, 1956, **48**, Mar., Part 1, 351–359). A review of uses other than as fuel, including

metallurgical coke production and production of metal chlorides from oxides. 58 metallurgical and 81 other references.

Flame Research at Ijmuiden. (*Engineer*, 1955, **200**, Nov. 25, 756–758, Dec. 2, 808–809). This article describes the work carried out by engineers from Britain, France, the Netherlands, Sweden, Belgium and the U.S.A. into the behaviour of flames, the mechanism of combustion, the behaviour of furnaces and furnace plant. The work is supported by the glass, the iron and steel, oil, gas and other sections of industry and by a number of research organizations in various countries.—M. D. J. B.

The Internal Structure of Flame Reaction Zones. G. Dixon-Lewis. (*Gas Council, Res. Comm.*, G.C. 29, 1955, Nov., 1–30). A short account is given of recent work on the internal structure of flames travelling through gas/air mixtures in which the flow is streamline. Some possible applications of the work to the solution of practical problems in gas utilization are considered.—B. G. B.

Flame Geometry as a Factor in Industrial Heat Processing. R. C. Le May. (*Steel Processing*, 1955, **41**, Sept., 587–592). The author discusses the various applications of gaseous fuels for furnaces and for torches and burners for localised heating (particularly surface hardening). The importance of flame geometry is emphasized, and its control by burner design and fuel composition is dealt with. Several types of burners and torches for special applications are described and illustrated.—P. M. C.

Differential Thermal Analysis and Its Application to Fuel Science and Technology. J. B. Nelson. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19**, Sept.-Oct., 502–531). A comprehensive review of differential thermal analysis is given. Development and use of the method are described with particular reference to applications of interest in fuel science and technology (240 refs.).—D. L. C. P.

Automatic Steam Generation with Steel Plant By-Product Fuels. J. A. Kotsch and H. W. Peth. (*Iron Steel Eng.*, 1955, **32**, Dec., 133–136). A brief description is given of the automatic controls, largely pneumatic, on the coke-oven gas fired boilers installed at the Hazelwood plant of Jones and Laughlin's.—M. D. J. B.

Some Mechanical Properties of Coal. F. J. Hiorns. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19**, Nov., 533–543). Information on the measurement of the breaking strength, and the elastic and rheological properties of coal is reviewed. (28 refs.).—D. L. C. P.

Coke and By-Products in 1954. I. E. Madsen. (*Iron Steel Eng.*, 1955, **32**, Dec., 85–91). The salient statistics of the United States coke industry are given including data on coke-oven operation and coal-chemical materials produced.

Coke-Oven Chamber Width. B. I. Kustov. (*Stal'*, 1955, (5), 391–396). [In Russian]. The effects of coke-oven chamber width on coking time and the properties of the coke are considered on the basis of large-scale test results.—S. K.

The Fuel and Power Resources of Germany and their Utilization. W. Gumz. (*J. Inst. Fuel*, 1955, **28**, Aug., 393–411). The position of coke ovens, iron and steelworks and producers is included in this survey of the supply and demand of fuel and power in Germany. A scheme to produce and use ferrocoke is mentioned.—D. L. C. P.

The Influence of Grinding on Coke Quality. V. Charvát. (*Paliva*, 1956, 36, (2), 40–43). [In Czech]. Commonly used methods of estimating coke quality from granulometric curves are shown to be inadequate. A simple, but in practice sufficiently accurate method of assessing particle size distribution is recommended. This is based on the use of only two sieves of approximately 10 and 100 mesh size respectively.—P. F.

Blockage and Corrosion of Plate and Tubular Recuperative Air Heaters. B. Lees. (*J. Inst. Fuel*, 1955, **28**, Sept., 433–440, 450). It is shown that suitable air-velocity distribution at the inlet to air heaters is an important factor in reducing blockage and corrosion. Practical modifications to air heaters are recommended.—D. L. C. P.

The Calculation and Construction of Steel Recuperators. J. Fleurquin. (*Chaleur et Ind.*, 1955, **36**, Dec., 365–369.) After a discussion of the theories involved in recuperator design, types of recuperator are indicated.—T. E. D.

Development of the "Schack" Metallic Recuperators at Arbed. M. Steffes and A. Graff. (*Chaleur et Ind.*, 1955, **36**, Dec., 375–382). The characteristics of metallic recuperators of the Schack type installed at the Belval division of Arbed are tabulated. The layout and mode of operation of the recuperators, with the furnaces they serve, are discussed with diagrams. Reference is made to performance data obtained over a ten year period. Discussion.—T. E. D.

Coking Coals—Scarcity or Abundance? E. Burstlein. (*Centenary Congress of the Société de l'Industrie Minérale, June*, 1955, SA. 4, 1–16). Alarm over decreasing European reserves of coking coal is dismissed because modern methods of coal preparation and the use of stabilizing additives have brought a great increase in the range of coals suitable for coking. Modern methods of coal study and principles of producing coking mixtures are discussed, with emphasis on the "Longwy-Burstlein" process of cleaning, grading, and blending coal.—E. C.

Some Characteristics of Lorraine Coals. E. Schwarz. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, SA 2, 1–5). A brief survey is given of the various types of Lorraine coal. A variation with depth is noted, approximately in agreement with Hilt's law. Coking properties are shown to deteriorate with increasing oxygen content. Low sulphur and chlorine contents are noted.

Queensland Coals—Physical and Chemical Properties and Classification. A. J. Norman. (*Queensland Gov. Min. J.*, 1955, **56**, Aug., 553–600). A detailed report on Queensland coals is presented. Their properties are compared with foreign coals. All data refer to present day grades of coal.—B. G. B.

Granular Flow Through Bunkers. J. C. Richards. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19**, Apr., 145–158). A review of problems associated with the design of bunkers is given. Remedies for degradation, segregation, bridging etc., are considered. (50 refs.).—D. C. L. P.

The Coke and Iron Division of IRSID. C. G. Thibaut. (*Rev. Tech. Luxembourg.*, 1955, **47**, Apr.-June, 65–74). A review of the activities at this research department is presented. Reference is made to the internal organization at the department and to 65 published articles.—B. G. B.

Injury Experience in the Coking Industry, 1953. S. T. Reese and N. W. Kearney. (*U.S. Bur. Mines Bull.*, No. 553, 1955). Statistics relating to injuries in the American Coking Industries are presented and discussed.—B. G. B.

Methods for the Analysis and Testing of Coking Coals and Cokes in Coking Plant Laboratories. A. Thomas and R. Wildenstein. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, SA 3, 1–5). Established methods of chemical analysis, mechanical and physical testing for coals and coke are outlined. References, but no details, are given for the various tests.—E. C.

The Production of Special Cokes. C. Abramski. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, SA8, 1–10). Taking two special cokes as examples, an electrode coke and a coke for cupola furnaces, it is shown that coke of specific properties can be produced by careful attention to selection of coking mixtures, blending, selective grinding, and correct conditions in the coking ovens. Various factors affecting coke structure and quality are discussed.—E. C.

Utilisation of Semicoke from Peat as a Component of Coking Blends. E. M. Taits and G. E. Fridman. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1954, (4), 100–106). [In Russian]. The use of semicoke from peat as a diluent in coal blends for the production of metallurgical coke was investigated. It was found that certain coals can be successfully replaced by semicoke from peat.—V. G.

Controlling Gas Flows in the Coal Charge During Coking. N. P. Khudokormova. (*Stal'*, 1955, (4), 295–301). [In Russian]. Possible ways of controlling the movement of gas in the charge during coking are discussed on the basis of laboratory and full-scale experiments with a variety of coals and coking conditions.—S. K.

The Influence of Cake Composition on the Cracking of Coke. R. Loison and A. F. Boyer. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, SA 1, 1–16). Laboratory studies of the contraction and cracking of coke during the coking process are described in detail. Results are compared with plant observations and the importance of the contraction rate in the vicinity of the solidification point is stressed. Cracking prevention by addition of high grade coals and inert materials is discussed.—E. C.

Theoretical Problems of the Formation of Coke and the Charging of Coal. S. G. Aronov and L. I. Nesterenko. (*Stal'*, 1955, (8), 678–687). [In Russian]. The production of good blast-furnace coke is considered in the light of theories of the coking process and operating experience.—S. K.

The Use of Radioactive Sulphur for An Investigation of Thermochemical Transformations of Sulphur Compounds in Coal During Coking. A. Z. Kulishenko and K. P. Medvedev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tek. Nauk*, 1955, (7), 145–149). [In Russian]. By comparing sulphur distribution between various carbonization products with and without addition of radioactive sulphur in the form of pyrite, the character of the distribution of individual forms of sulphur between decomposition products during carbonization of coal was determined. It was found that about 62% of pyritic and 63% of organic sulphur remains in coke.—V. G.

The Behaviour of Pyritic and Organic Sulphur During Coking of Coals and Coal Blends. K. P. Medvedev and V. M. Petropolskaya. (*Izvest. Akad. Nauk SSSR, Otdelenie Tek. Nauk*, 1955, (8), 134–139). [In Russian]. The behaviour of sulphur during coking of individual coals and blends of coals from the Donets basin was investigated using radioactive additions of pyritic sulphur. It was found that on heating, hydrogen sulphide evolved up to a certain temperature (350–500° C, depending on coal rank) originates from pyritic sulphur only; with further increase of temperature, the concentration of organic sulphur in the hydrogen sulphide evolved increases. The temperature at which the evolution of organic sulphur begins and the total amount removed on carburization depends on the rank of coal.—V. G.

Blending Coke and Smokeless Fuel. G. Cellan-Jones. (*Coke Gas*, 1956, **18**, Feb., 52–55, 61). The "Coal Logs" process, in which a non-coking coal is carbonized on a wire mesh belt and discharged into a screw extrusion press while still plastic, and extruded into "logs" about 3 in. dia. and 1 ft. long is described. The plant can also be operated at a temperature above the plastic range of the coal to produce a char suitable for blending with coking coal to reduce shrinkage during coking, and thereby producing metallurgical coke with improved shatter strength.—T. E. D.

Properties of Different Size Fractions of Metallurgical Coke. A. S. Bruk and Z. A. Volkova. (*Stal'*, 1955, (8), 688–692). [In Russian]. An account is given of an investigation of the mechanical and aerodynamical properties of various size fractions of coke samples obtained from railway wagons or transporters conveying coke to blast-furnace plants. Coke in the size range 40–80 mm was found to have the best properties and a scheme for increasing the content of this range is proposed.—S. K.

Investigations of the Properties of Metallurgical Coke. H. Schenck and H. Esch. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1421–1425). The authors refer to the mechanical, thermal, and chemical demands on coke. They discuss the effect of simple compressive loads on coke under various conditions, and the determination of the strength of the coke. Experimental results are given.—A. C.

The Continuous Determination of the Specific Carboxyreactivity of Coke. M. Bastick and H. Guérin. (*Compt. Rend.*, 1955, **240**, Jan. 10, 198–200). Since the carboxyreactivity of a coke varies during abrasion, the initial carboxyreactivity should be replaced by a specific term which takes account of this variation. A continuous method of determining the specific carboxyreactivity which is defined as the speed of gasification at any instant, is described for a number of different cokes.—G. E. D.

Carbonizing Tests with Tuscaloosa Oven 1952-53. J. B. Gayle and W. H. Eddy. (*U.S. Bur. Mines Rep. Invest.*, No. 5125, 1955, Apr.). Tests carried out on a half ton experimental coke oven are reported. The work has mainly been concerned with the reproducibility of the results.

Cupola Coke. M. Decrop. (*Fonderie*, 1955, Sept., 4693–4698). The factors affecting the quality of cupola coke are reviewed and discussed in detail. The sampling of coke and the tests that may be used to determine its strength are also considered.—B. C. W.

Metallurgical Coke in Canada. J. R. Wallace, E. P. Duchemin and W. Snow. (*Canad. Min. Met. Bull.*, 1955, **48**, Oct., 654–662). Canadian coal and coke production is surveyed with particular reference to Cape Breton coals. Coking properties of these coals are given and coking practice is described.—T. E. D.

Reclamation of the Incandescent Heat of the Coke in Coke Oven Plants and Gas Works. W. Hersche. (*Maschinenbau Wärmewirtschaft*, 1956, **11**, Jan., 1–11; Feb., 33–45). The principles and applications of dry cooling as an alternative to coke quenching are outlined; plants for the recovery and use of the incandescent heat are described and illustrated.

New Gas Producers of Large Capacity Burning Coal for the Production of Pure Gas. P. Heurtey. (*Mém. Soc. Ing. Civils France* 1955, **108**, Nov.-Dec., 535–556). The design and operating characteristics of gas producers in commercial use are described. The recuperation of the sensible heat of the exit gases and the removal of solid and condensible impurities in the gas are discussed. Results obtained with a new gas producer at Société Creusot are described in detail. This is very flexible in operation and has burnt coal at the rate of between 30 and 105 tons in 24 hrs.—B. G. B.

Heurtane Gas and Its Industrial Production. L. Gagnaire. (*Mét. Constr. Mécan*, 1955, **87**, Nov., 911–915). The principles of the Heurtane gas producer are described. In this coal is burnt, the sensible heat of the exit gas is used to heat the incoming air and condensible oil and tar is removed by scrubbers.—B. G. B.

Catalytic Effects of Cobalt, Iron, Nickel and Vanadium Oxides on Steam Carbon Reaction. W. M. Tuddenham and G. R. Hill. (*Indust. Eng. Chem.*, 1955, **47**, Oct. 2129–2133).

Flow Experiments in Studying Kinetics, Role of Diffusion and Influence of Flow Pattern in Gasification Reactions. S. Ergun. (*Indust. Eng. Chem.*, 1955, **47**, Oct., 2075–2080). An account of experiments on the oxygen-steam-carbon-carbon dioxide system is given.

Effect of Changes in Gas Composition on the Utilization of Fuel Gases. E. X. Schmidt. (*Iron Steel Eng.*, 1955, **32**, Dec., 110–118). The paper gives a number of curves which can be used to determine the suitability of substituting one type of fuel gas for another. Data are given for natural gas, propane-air gas, coke oven gas, blast furnace gas and producer gas.—M. D. J. B.

Industrial Applications of Dual-Fuel and Combination Burners. R. J. Reed. (*Indust. Heating*, 1955, **22**, Oct., 2020–2026). Applications and operation of burners that can burn gas and/or light oil are described.—A. D. H.

Burners for Siemens-Martin Furnaces. I. Experience with the Brinkmann Oil Burner. K. Fettweis. (*Stahl u. Eisen*, 1955, **75**, Nov. 17, 1553–1554). Existing furnaces, their conversion from gas to oil firing, and the operation of the Brinkmann burner are described. Operational and economic aspects are discussed. New installations are referred to. **II. Experience with STEC and Krause Burners.** M. Hauck. (1554–1555). Tests on STEC, Krause, and Schieldrop burners are described. The same performance was obtained with oil firing as with coke oven gas and brown coal dust. The Krause burner was cheaper than the STEC burner. The use of coal-tar oil is referred to, and the effects of pitch firing on the checker chambers. Oil is stated to have the advantage over gas. **III. Conversion of Cold Gas Furnaces to Oil Firing with Special Burners.** H. Clees (1555–1557). The difficulties of conversion and the effects of nozzle layout on operation are reviewed. A new and simple type of burner is described. **IV. Experience with the Unimul Burner.** K. Guthmann. (1557). The conversion of a furnace from producer gas to simple oil firing is described. Oil atomisation with preheated compressed air is used, and good regulation of flame length obtained.—A. C.

Oil Firing in an Integrated Steelworks. H. Weineck. (*Stahl u. Eisen*, 1955, **75**, Oct. 20, 1375–1383). Oil firing was resorted to as a result of a shortage of coke oven gas. The heat utilisation and proportioning in an integrated steelworks is reviewed. Oil firing of melting and re-heating furnaces in general, and the subject of burners in particular, are discussed, and technical, organisational, and economic aspects are considered. The advantages and disadvantages of oil heating are analysed and compared.—A. C.

AIR POLLUTION AND SMOKE

Dust and Gas Generated by Steam-Generators, and their Distribution in the Atmosphere. K. Schwarz. (*B.W.K.*, 1956, **8**, March, 97–109). An analysis is made of the nature and effects of industrial air-pollution, and methods of solution of the problem are outlined.—P. F.

Dispersal of Dust Particles from Elevated Sources. G. T. Csanady. (*Australian J. Phys.*, 1955, **8,** Dec., 545–550). An extension of Sutton's work on the diffusion of gases and particles from industrial stacks.

Modern Electrical Precipitation. H. J. White. (*Indust. Eng. Chem.*, 1955, **47,** May, 932–939). Basic principles are outlined, equations for efficiency are derived, and laboratory confirmation and engineering applications are described. The paper is included in a symposium on air pollution.

Researches into Factors Affecting Electro-precipitation. J. R. A. Lakey and W. Bostock. (*Trans. Inst. Chem. Eng.*, 1955, **33,** 252–263). The resistivities of iron oxides and pyrites and the effects of particle size, conditioning, and humidity are included.

A Recording Smokemeter. A. C. Jason. (*Instrument Practice*, 1956, **10,** Feb., 133–134). Smoke density is measured by determining its optical density in terms of a reference column, by means of a rotating optical wedge and barrier layer photocell system.—L. D. H.

TEMPERATURE MEASUREMENT AND CONTROL

Some Remarks on the Measurement of Furnace Temperatures by Thermocouples. A. M. Kruithof. (*Lab. N. V. Philips' Gloeilampfabrieken, Separaat*, 2209, reprinted from *Proc. 3rd Internat. Congress on Glass, Venice*, 1954, 529–539). An account of the suction pyrometer or aspiration pyrometer and its use in glass furnaces and recuperators is given.

Pyrometry—Some Suggestions for Maintenance. L. Walter. (*Steel Processing*, 1955, **41,** July, 435–438). Various types of thermocouple installation are briefly described, and the use of total radiation pyrometers is discussed. Schematic circuit diagrams are presented, and the important aspects of correct installation and subsequent care of temperature measuring equipment are emphasized.—P. M. C.

The Milliscope Pyrometer : A Quick Response Instrument for Registering and Controlling Temperature Changes on Rapidly Moving Objects. (*Automobile Eng.*, 1955, **45,** Oct., 437, 438). This instrument functions on the principle of the incandescent lamp pyrometer, but the comparison of the radiated energy from the work and that from the calibrated lamp is effected by means of a lead sulphide cell. The reaction is practically instantaneous. The instrument was designed and is produced by Hartmann and Braun, solely for use on Peddinghaus flame hardening machines.—P. M. C.

Suction Pyrometers in Theory and Practice. T. Land and R. Barber. (*J. Iron and Steel Inst.*, 1956, **184,** Nov., 269–273). [This issue].

Automatic Temperature Control of Oil- and Gas-Fired Furnaces. L. Walter. (*Metal Treatment and Drop Forg.*, 1955, **22,** Apr., 150–152). The various available methods of furnace temperature control are briefly described, and the factors influencing the selection of a particular method are discussed. The requirements of control plant and some economic aspects are briefly referred to.—P. M. C.

REFRACTORY MATERIALS

Refractories for the Bottom Pouring of Steel. G. G. Aristov. (*Ogneupory*, 1952, **17,** 364–370). A study of erosion in runner systems for rimming and killed steel is reported. The material remaining in the runners was examined.

Thermal Decomposition of Dolomite Crystals—A Solid State Reaction. R. A. W. Haul. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 431–440). [In German]. X-Ray powder photographs and thermo-gravimetric studies are described as well as differential thermal analyses. These show that MgO is first formed, the mixed crystals opacifying. The effects of crystal size and orientation are considered.

Clay Deposits of the Arandelovac Basin. T. Lupibereza. (*Rudarsko-Metalurški Zbornik*, 1954, No. 2, 135–155). [English Summary]. The geology of the region is described in detail with special reference to the refractory clays. Their present uses and future possibilities are discussed.

Study of Iron Oxides in the Burning of Magnesite. O. Quadrat and M. Beránek. (*Coll. Czechoslovak Chem. Comm.*, 1949, **14,** No. 1–2, 59–65). [In French]. When magnesite containing 2·5% FeO as $FeCO_3$ was burnt at 900–1000° in a current of nitrogen all the iron was converted to ferric oxide. In air, the surface iron is oxidised by the oxygen and that in the interior of the grains by CO_2. Oxidation by CO_2 begins at 320° and reaches 99–99·3% between 860–1170°. At higher temperatures less Fe_2O_3 is formed and at 1300° it is mainly Fe_3O_4. Well-burnt magnesite does not form Fe_3O_4 and its capacity for sintering depends upon the presence of tervalent iron. Fe_3O_4 in the interior of the grains forms ferrites at 1500°.

Fundamentals of Gas-Permeability Determination for Fire-Resistant Materials. L. Žagar. (*Arch. Eisenhüttenwesen*, 1955, **26,** Dec., 777–782). The literature of the subject is reviewed, and the determination of the specific permeability of magnesite, fireclay and silica brick is described. The use of permeability units is discussed.

Magnesite. N. K. M. Aiyengar. (*Bulletins of the Geological Survey of India*, 1953, Ser. A, No. 6). A general discussion of the industry.

Differential Thermal Analysis of Clays. C. Pelham. (*Rudarsko-Metalurški Zbornik*, 1954, No. 2, 157–171). [German Summary]. On the basis of thermal analysis the clays are characterised in terms of kaolinite, montmorillonite and sericite, the temperatures at which exothermic processes begin are given.

Stress-Endurance of Sintered Alumina. L. S. Williams. (*Trans. Brit. Ceram. Soc.*, 1956, **55,** May, 339–368).

Determination of the Size Distribution of Pores in Refractory Materials. L. Žagar. (*Arch. Eisenhüttenwesen*, 1955, **26,** Sept., 561–562). The behaviour of refractories depends mainly on the size, form, number, and distribution of the pores. The effect of these quantities was determined by a displacement method (using water and air) based on Cantor's equation. The specimens were saturated with water, and the water then gradually removed by means of compressed air. The rate of flow of air through the saturated specimen was measured in relation to the pressure required for the expulsion of the water, and the size-distribution of the pores was determined from the resulting curves. The range of sizes in firebricks was found in this manner, the results showing that the pore-sizes depend very much on the porosity of the material used in manufacture.—A. C.

The Refractoriness of Some Types of Quartz and Quartzite. F. Sandford and S. Fransson. (*Acta Polytec.*, 1955, **4.,** No. 9). It is shown that direct determination of the refractoriness under load of quartz and quartzite is necessary if information is required concerning the softening conditions during the early stage of the firing.—B. G. B.

The Behaviour of Silica Brick in the Roofs of Siemens-Martin Furnaces. (*Forschungsberichte des Wirtschafts- und Verkehrsministeriums Nordrhein—Westfalen*, 1954, No. 90, pp. 49). An account is given of investigations of compositions, melting-points, polymorphic transformations, etc., with the $CaO—Al_2O_3—SiO_2$ diagram.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The New Blast Furnace of the Society d'Espérance-Longdoz at Seraing-lez-Liège (Belgium). (*Génie Civil*, 1955, **132,** Aug. 1–15, 309–310). A general account is given of the new installation with an output of 800 t daily.

Blast-Furnace for ISCOR. (*Brit. Engineering*, 1956, **38,** May, 372). Some details are given of a blast furnace of hearth diameter 25 ft and output over 1000 tons/day to be built by Ashmore, Benson, Pease & Co.—K. E. J.

Jones and Laughlin Aliquippa Works. T. J. Ess. (*Iron Steel Eng.*, 1956, **32,** Nov., 74–103). This article gives a very full description of the works. Details are given of the raw materials, coke oven, blast furnace and steel making departments as well as of the wide range of mills and engineering services.—M. D. J. B.

A Welded Blast Furance and Ancillary Equipment. T. Birchall. (*Welder*, 1955, **24,** July/Sept., 53–56). The welding of a blast furnace and equipment is described.—U. E.

Evaluation of Conduction Losses in Cowper Stoves. D. Sanna. (*Centenary Congress of the Société de l'Industrie Minérale*, June, 1955, Sf2, 1–11). The principles are discussed of using Fourier's method of calculating conduction to determine this type of heat loss in Cowper stoves. A complete calculation is shown to exemplify the method.—E. C.

Studies of Blast-furnace Assessment. J. M. Ridgion and A. M. Whitehouse. (*J. Iron Steel Inst.*, 1956, **184**, Nov. 249–257). [This issue].

Aids to Blast Furnace Studies. Air Flow in Beds of Granular Solids. J. B. Wagstaff and E. A. Nirmaier. (*Indust. Eng. Chem.*, 1955, **47**, June, 1129–1135). An account of experiments on a model system from which formulæ for pressure drop are obtained and tested.

Sulzer Axial Blowers for Furnace Blast. A. Aguet. (*Sulzer Tech. Rev.*, 1955, **37**, No. 3, 1–18). An illustrated account of the design and working characteristics of the blast-furnace gas turbine and blower.

Rational Distribution of Stock in a Blast Furnace. T. A. Tesch. (*Iron Steel Eng.*, 1955, **32**, Dec., 125–131). A new charging and distributing system is described which is designed to charge more or less of larger or smaller particles in practically any concentric horizontal ring of the stock line, as desired by the operator.—M. D. J. B.

Desulphurization of Molten Pig Iron with Pulverised Lime. B. Kalling. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 913–920). [In English]. A description of the process developed at the Domnarvet Steelworks in which the lime remains solid and is brought into contact with the metal in a rotating furnace. The furnace is described and the course of the reaction traced graphically.

On Phase Transformations in Blast Furnaces. I. P. Bardin. A. V. Rudneva and L. M. Tsylov. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (5), 123–128). [In Russian]. On the basis of data collected during exploration of blast furnaces smelting ordinary pig iron, ferrosilicon and ferromanganese, phase transformations taking place at various furnace levels are discussed.—V. G.

A Study of the Changes in Static Pressure Along the Height of a Blast Furnace and Measurements of Hearth Temperatures. N. N. Chernov, I. F. Domnitskii and G. S. Manchenko. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (4), 63–72). [In Russian]. A study of the changes in the static pressure along the height of furnaces indicated that under a given set of operating conditions, there is a certain pressure drop between tuyers level and top at which the furnace operates smoothly. An attempt was made to control the furnace operation by an automatic regulator which by increasing or decreasing the top pressure maintained pressure drop across the furnace at a predetermined constant value. When this automatic regulator was in operation the furnace worked smoothly, but the operation of the instrument was limited to short periods only because an increase of top pressure above 0·7 atm. (which was often required) was impossible from strength considerations.

PRODUCTION OF STEEL

Technical and Metallurgical Developments in Steel Production in the German Democratic Republic. K. Lüdemann. (*Neue Hütte*, 1956, **1**, Jan., 133–147). More than 80% of the steel in the German Democratic Republic is produced in open hearth furnaces. The years 1946–1951 were devoted to reconstruction, 1952–1953 to consolidation : in 1954 steel works were forced to use 45–50% of steel pig instead of the usual 25–30%. Some practical examples of this conversion are given.—L. J. L.

Scrap Preparation and Contamination. R. F. Kuhnlein. (*Iron Steel Eng.*, 1955, **32**, Dec., 120–123). The various contaminants of scrap are reviewed and the measures which can and should be taken to improve matters are described.

Durgapur Steel Project. (*Far East Trade*, 1956, **11**, May, 484–485). An account of the construction work projected with an outline of development of the scheme.

Bethlehem-Seattle Marks 50th Year ; Fully-Integrated Plant Fills NW Needs. H. E. Jackson. (*Western Metals*, 1955, **13**, May, 59–61). A brief account is given of the facilities and services offered by the Seattle plant of Bethlehem Pacific Coast Steel Corp.—P. M. C.

Economics of Oxygen Steelmaking. (*Steel*, 1955, **137**, Nov. 21, 100–103). An outline of the oxygen converter steelmaking process is given, and some plant and operating costs are predicted.—D. L. C. P.

Studies on the Decarburisation Reaction of Molten Fe–C Alloys. I. Measurement of the Specific Constant of the Decarburisation Velocity with Oxygen Gas. K. Niwa and Y. Katsufuji. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, June, 271–274). [In Japanese]. The decarburisation of iron containing 4% of carbon was determined in experiments in which air was directed at the metal at 1430–1780°C. The velocity constant and activation energy were found. The rate-determining reaction is that between carbon and dissolved oxygen.—K. E. J.

Further Contribution to the Spectrum of the Bessemer Flame. K. S. Garger, D. Umnov and G. D. Krivulya. (*Izvest. Akad. Nauk SSSR, Seriya Fiz*, 1955, **19**, (2), 186–188). Lines in the spectrum are shown and identified from 3960–5500Å. Photoelectric observation of the changes in the flame is possible.

The Standardisation of the Principal Dimensions of Open Hearth Furnaces. S. Cernoch. (*Neue Hütte*, 1956, **1**, Jan., 150–156). Orthodox methods of open hearth furnace design are reviewed. The use of maximum heat consumption as a starting point for calculations is advocated. The attempt is made to express fundamental data as a function of furnace size by means of graphs and simple mathematical equations.

A New Profile for the Heating Chamber of the Siemens-Martin Furnace. F. Bartu and E. Boelens. (*Stahl. u. Eisen*, 1956, **76**, Feb. 9, 152–158). A new furnace profile with inwardly sloping walls is stated to give considerable economy of material in the arch, improved flame distribution, and better heat transfer. The life of inwardly sloping front and rear walls could only be evaluated by experiment, and a 35 metric ton Siemens-Martin furnace was modified for the purpose. The results are described and substantial gains claimed.—A. C.

Kinetics and Mechanism of Desulphurization in Slag–Metal Systems saturated with Carbon. G. Derge and W. O. Philbrook. (*Rev. Mét.*, 1955, **52**, Dec., 995–1000). Desulphurization is shown to be a first-order reaction and three processes are distinguished, partition in slag, and reactions with lime (S) and carbon (O). Surface tension data show that slags with lower Gibbs coefficients desulphurize best.

Chromium Reactions in Acid and Basic Furnaces. S. F. Carter. (*Amer. Inst. Min. Met. Eng.*, 1955, Preprint). In order to gain a better understanding of chromium reactions and their equilibrium tendencies, the author has taken slag samples at various stages from a number of production heats, both acid and basic, of 2–3 tons for steel castings. Changes in slag composition and bath composition are correlated, and the effect of furnace reactions on chromium recovery is discussed.—G. F.

Methods of Increasing Open Hearth Production. J. W. Teskey and W. L. Murphy. (*Iron Steel Eng.*, 1955, **32**, Nov., 135–139). The author discusses various means of increasing O.H. furnace output. He lists as most important :—good scrap, a minimum flux burden, good burner design, better refractories, full instrumentation and finally good personnel.

The Modern Manufacture of Steel Plate for Shipbuilding. T. F. Pearson. (*N.E. Coast Inst. Eng. Shipbuilders*, Advance Copy, Jan. 13, 1956). A survey of the manufacturing techniques used to make steel plate is presented. Steelmaking by the acid and basic processes is described together with ingot practice. Modern rolling mill construction is explained and the special finishing operations for making plate for shipbuilding are described. The chemical and physical properties of steel plate are considered and the development of improved steels having enhanced resistance to brittle fracture is reviewed.—B. G. B.

Oxygen Converter Bids As Steel Industry's Bright New Tool for Lower Cost Production. J. W. Irvin. (*Western Metals*, 1954, **12**, Nov., 43–45). The oxygen converter process for the production of high quality low-carbon steel is briefly described, particularly from the economic viewpoint. It is pointed out that the process, which originated in Europe, has the speed and economy of the Bessemer process plus the product quality of the open hearth. The author refers to the growing interest of American steelmakers in this field.

Behaviour in Blowing of Different Types of Bottoms. Demarteau. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1956, **13**, (1), 147–155). The relations between pressure and volume of air blown in converters with 172-tube and 24-tuyere bottoms are compared. Curves showing variations with time throughout blows in the different converters are discussed and some anomalies are explained.—T. E. D.

Internal Inspection of Open-hearth Furnace Operation: Design and Application of Furnace Scanning Periscope. C. Burns. (*Iron Coal Trades Rev.*, 1956, **172**, Jan. 20, 133–136). The author describes the design and construction

of the B.I.S.R.A. scanning periscope, which allows viewing of the inside of O.H. furnaces during operation. The results of trials are discussed and illustrated, and potential applications are mentioned.—G. F.

Soda Ash Desulphurization: A Study of the Practice at Nine Works. C. E. A. Shanahan. (*Iron Steel*, 1956, **29,** Jan., 9–14; Feb., 45–48). Details are given of the soda-ash desulphurization process as practised at nine different works, with particular attention given to the soda-ash slag and fume problems. Results are quoted and it is concluded that, given adequate arrangements for skimming off the slag and removing the fume, the process is very efficient for desulphurizing iron.—G. F.

Experience in the Organization of Cost Calculations in the Open Hearth Plant. V. S. Kushpel'. (*Stal'*, 1955, (4), 356–358). [In Russian]. The system used at the Serov Works for cost calculations involved in the operation of incentive schemes in the O.H. plant is outlined.—S. K.

Hydrogen in Metal in the Course of Acid Open Hearth Process. M. M. Karnaukhov and A. Kh. Urazgul'deev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955 (8), 93–99). [In Russian]. Changes in the hydrogen concentration in metal in the course of acid open-hearth process were investigated. Quenched samples were analysed for hydrogen by vacuum heating at 700° C. In the finishing operations it is indirectly related to the reduction of silcion. Acid open-hearth slag is to some extent permeable to water vapour from the furnace atmosphere. Changes in hydrogen concentration in metal above a minimum value (which is characteristic for a given furnace) depend on the velocity of decarburization. A decrease in the hydrogen content can take place only if the boiling velocity is above a certain critical value.—V. G.

Improving the Technology of Open-Hearth Smelting Working the Scrap-Ore Process. Ya. A. Shneerov and A. N. Morozov. (*Stal'*, 1955, (4), 312–328). [In Russian]. The present article deals with new instructions on the production of quality steels in basic O.H. and is based on co-operative work by research and works staffs in the U.S.S.R. The high incidence of incorrectly proportioned charges at some works is attributed to lack of standardization of pig-iron and scrap composition and to fluctuation in ore composition. Examples of present fettling practice and of defective organization of this work are briefly considered. This is followed by a more detailed discussion of charging, including the relation of the temperature of the solids to time and the duration of melting down of the whole charge to the duration of charging of the metallic part of the charge. Changes in slag composition with time, the desulphurization and dephosphorization reactions and flushing practice are dealt with. The article concludes with consideration of finishing practice including slag flushing, the oxygen content of the metal during the boil, the presence of non-metallic inclusions, changes in the hydrogen content of the metal, the behaviour of manganese, the iron oxide content of the slag and deoxidation.—S. K.

Mixing of Metal and Slag in Open-Hearth Furnaces. A. I. Osipov, L. A. Shvartsma, M. T. Bulskiĭ and A. G. Alimov. (*Stal'*, 1955, (8), 709–713). [In Russian]. In the investigation described the mixing of metal and slag under the conditions prevailing in 350-ton O.H. furnaces was studied with the aid of radioactive phosphorus. Very small additions became uniformly distributed throughout the slag and metal in 60–70 min. The curves of distribution against time indicate the diffusional nature of the process, and an estimate has been made of the coefficient of turbulent diffusion of phosphorus in liquid steel. The tracer technique worked satisfactorily and further experiments with radioactive elements which do not pass between the liquid phases (e.g. cobalt and calcium) are envisaged.—S. K.

Coreless Induction Furnaces. Mains-Frequency Sets for Melting Scrap and Swarf. (*Engineering*, 1956, **180,** Dec. 2, 771–772). This article describes the coreless induction mains frequency furnace, particularly suitable for producing a melt of exact composition from scrap, swarf, and borings. The introduction of this furnace into the U.K. is due to Birlec Ltd., Birmingham.—M. D. J. B.

Stabilization of the Temperature Conditions of Electric Resistance Furnaces. V. V. Vernikovskiĭ and I. I. Yamzin. (*Zavodskaya Laboratoriya*, 1955, **21,** (4), 492–493). [In Russian]. A temperature regulating arrangement, suitable for resistance furnaces working at high temperatures (1500–2500° C), is described. For a carbon-element furnace the power was kept within $\pm 0{\cdot}5\%$ of the required mean value.

Mains Frequency Coreless Induction Furnace. (*Light Metals*, 1956, **19,** Mar., 88–89). The furnace developed by Otto Junker G.m.b.H. and shown in Sheffield, Birmingham, and London in October is described.

Mains-Frequency Coreless Induction Furnaces. (*Engineer*, 1955, **200,** Nov. 11, 701–702). This article outlines the principles of the design and manufacture of mains-frequency coreless induction furnaces. These furnaces are now built in the U.K. by Birlec Ltd.—M. D. J. B.

Development of American Electric Steel Production. F. Sommer. (*Stahl u. Eisen*, 1955, **75,** Dec. 1, 1649–1651). The production of highly heat-resistant alloys for jet power plant, nitrogen in stainless steel, recovery of chrome from slag, solidification of steel in the ingot mould, inclusions originating from linings, and spectrochemical determination of grain size are the subjects work upon which is reported.

Ways of Improving the Quality of Ball-Bearing Steel. Ya. M. Bokshitskiĭ. (*Stal'*, 1955, (4), 370–371). [In Russian]. The proceedings at a recent discussion, organized by the Central Research Institute for Ferrous Metallurgy, of ball-bearing steel production problems are outlined. Recommendations for further work are listed.—S. K.

Improving the Quality of Ball-Bearing Steel. M. I. Kolosov, I. Ya. Aĭzenshtok, N. V. Keĭs and D. B. Royak. (*Stal'*, 1955, (5), 431–438). [In Russian]. The results are presented and discussed of investigations, carried out at the Chelyabinsk Metallurgical Works over many years, on the prevention of non-metallic inclusions in ball-bearing steel. Various methods of deoxidizing the steel were compared, the most promising being diffusional deoxidation with a carbide slag and ferrosilicon. Other factors dealt with include the time at which ferrochromium is added, the pouring temperature and the method of pouring. The evaluation of steel quality from the content of non-metallic inclusions is also dealt with.—S. K.

Progress of Special Steel Making Process in Japan. Y. Ishihara. (*Tetsu to Hagane*, 1955, **41,** July, 777–786). [In Japanese]. The development of crucible- and electric-furnace steelmaking is surveyed; in 1954 Japan had 142 arc furnaces, of total capacity $1{\cdot}1 \times 10^6$ ton, and 75 induction furnaces, of total capacity $1{\cdot}4 \times 10^5$ ton. Details are given of the latest furnace, ingot-making, and heat-treatment practice, including induction stirring, O_2 lancing, rapid control of H_2, hot-topping, projected continuous casting, and sub-zero cooling.—K. E. J.

Modern Steelmaking. Use of the Electric Arc Furnace. R. Wilcock. (*Elect. Rev.*, 1955, **157,** Dec. 23, 1217–1220). The author reviews the conclusions of the Battelle report on "Comparative economics of open-hearth and electric furnaces for production of low-carbon steel." The low capital cost of the electric arc furnace and the fact that all-scrap charges can be used, together with the short melting times, reduce the discrepancy in fuel costs. This advantage disappears if hot metal is used. It is concluded that the electric arc furnace may compete to some extent with the open-hearth process, particularly the acid process, for tonnage steels, provided that larger units are used than are available in Britain, and that open-hearth standards are adopted for S and P contents—i.e. if a single-slag technique is used.

Steel Making with Solid Slag. A. Giminez y Sanmartin. (*Inst. Hierro Acero*, 1956, **9,** Jan., 28–34. *Special Number*). [In Spanish]. After an introductory discussion of the meaning of quality as applied to steel, the author discusses various aspects of rapid quality-steel making with particular reference to the use of solid slags. The results of trials with three types of solid slag are given (these being made on top of a normal heat in an electric furnace). The most reliable type, made by adding sodium carbonate to a white falling slag and mixing when cold with calcium carbide, gave a reduction in sulphur of about 25% in steels of the 0·52% C, 0·70% Mn type.—P. S.

Gas Purging of the Molten Bath in the Electric Arc Furnace. A. J. Texter. (*Amer. Inst. Min. Met. Eng.*, 1955, *Preprint*). At Firth Sterling works, purging of the molten bath to eliminate dissolved gases and improve quality is carried out with oxygen, dried compressed air, and the plastic polytetrafluoroethylene ("Solo-H"). The particular merits of each and the practice adopted are outlined.—G. F.

Hydrogen Control through Flushing of Molten Steel in Electric-arc Furnaces. L. F. Barnhardt. (*Amer. Inst. Min. Met. Eng.*, 1955, *Preprint*). The use of dry air or argon flushing for hydrogen control is now routine at Atlas Steels

Ltd., and details of the practice are given. The reasons for discontinuing nitrogen flushing are given, and exceptions to the use of dry air are mentioned.—G. F.

Review of Electrometallurgy. M. Fourment. (*Mem. Soc. Ing. Civils France*, 1956, **109**, Jan.-Feb., 3–22). Electric furnaces of the resistance, induction and arc types are reviewed, particular mention being made of recent arc furnaces for steelmaking. Vacuum fusion techniques for the production of pure metals and alloys are also described. The present status of electrometallurgy is discussed.—B. G. B.

Stainless Steels. W. A. Luce. (*Indust. Eng. Chem.*, 1955, **47**, Sept., Part 2, 2023—2035). A comprehensive review for 1954. High-silicon irons and iron-nickel and austenitic iron-manganese alloys are mentioned. (198 references).

New Oxidation-resisting Steels made in the U.S. A. Roos. (*Génie Civil*, 1955, **132**, June 15, 232–234). Types of steels with compositions and properties are given. These comprise types 300 and 400 and ferritic steels, Carpenter No. 10 and No. 20 and AM-350. Heat treatments are given.

Controlled Expansion Alloys. (*Wiggin Nickel Alloys by Powder Metallurgy*, 16–18). An account of the iron alloys with 36–51% nickel is given, and of ternary alloys produced from them by powder metallurgy.

Progress in Stainless and Heat-Resisting Steels. J. Lomas. (*Eng. Boiler House Rev.*, 1956, **71**, Mar., 85–86).

The Cr-Mn-Ni Stainless Steels. A. Michel. (*Bull. Cercle Etudes Métaux*, 1955, **6**, Mar., 321–340). The need for conservation of nickel has led to the development of stainless type steels other than the normal 18/8 type. These steels are considered in detail and specifications for American, British and Swedish steels are given. The corrosion properties of the Cr-Mn-Ni steels are assessed.—B. G. B.

Alloys Rich in Nickel and Molybdenum. J. P. Montojo. (*Met. Elect.*, 1955, **19**, Nov., 67–74). [In Spanish]. Alloys of the 0–60–30, 20–50–8, and 15–60–18 chromium nickel-molybdenum type for resistance to strongly corrosive environments are described and typical applications are quoted. The compositions, mechanical and physical properties, and corrosion resistance of these alloys are reviewed and their machining, welding, and heat-treatment are discussed.—P. S.

Hot-Work Tool Steels : Their Composition, Heat-Treatment and Properties. E. Bishop. (*Metal Treatment and Drop Forg.*, 1955, **22**, Dec., 519–524). A brief survey is made of hot-work tool steels with particular reference to post-war German developments. An extensive experimental study of the softening of such steels during long-period holding at various temperatures within the tempering range is referred to. The compositions and main uses of the many steels considered are tabulated. The author's remarks are based mainly on two recent German reports in *Stahl und Eisen*, one by H. M. Hiller and the other by K. Bungardt *et al.* (5 references).—P. M. C.

Nimonic Alloys and other Heat-Resistant Materials in Sheet Form. H. E. Large. (*Metal Treatment and Drop Forg.*, 1955, **22**, Oct., 445–448). Details are given of some of the heat-resistant alloys used in the construction of modern gas-turbine aircraft. The properties and means of fabrication of 18/8 type stainless steel, which is used extensively for tail pipes, are reviewed.—P. M. C.

Alloys for the Chemical Process Industries (Molybdenum). J. Z. Briggs. (*Indust. Eng. Chem.*, 1955, **47**, Aug., 1513–1516). An account is given of corrosion-resisting alloys containing molybdenum : austenitic Cr-Ni, with Mo or Mo and Cn ; high-silicon irons ; and nickel-base alloys. The resistance of metallic Mo to corrosion is reviewed.

Effect of Crystallisation Conditions of the Steel on Ingot Defects due to Cracks. V. A. Efimov, V. I. Danilin and M. P. Lapshova. (*Stal'*, 1955, (7), 601–606). [In Russian]. In the investigation described, the shrinkage conditions and plastic properties of a wide range of killed steels during the solidification of a 6-ton ingot and the correlation between these conditions and ingot cracking were studied.—S. K.

Calculation of Dimensions of a Pouring System for the Casting of Steel. A. Sarajlić. (*Rudarsko-Metalurški Zbornik*, 1954, No. 1, 97–104). [French Summary]. An expression is given for the diameter of the inlet system at its narrowest point.

Calculation of Most Economic Cropping of Ingots for Wheel Rims. L. v. Bogdandy. (*Arch. Eisenhüttenwesen*, 1955, **26**, Dec., 783–786). The author discusses the determination of pipe depth at the top and bottom ends of ingots and describes a method of calculating the most economic cropping. He also deals with the best distribution for roughed-down ingots. He claims that improvements in cogging mill output were obtained in practice according to prediction.

Application of Continuous Casting to Steel. J. Savage. (*Metal Treatment and Drop Forg.*, 1955, **22**, July, 277–287). The present range of application of continuous casting to steel, either commercially or experimentally, is reviewed for eleven plants known to be operating on a wide range of steels. The basic differences between the three principal continuous casting processes so far applied are discussed from the point of view of preventing rupture of the billet skin in the mould. These processes are the Junghaus-Rossi reciprocating mould, the Babcock and Wilcock intermittent billet withdrawal from a fixed mould, and the flexibly mounted mould developed by BISRA. The possible uses of automatic methods for controlling the flow of steel into the mould and the withdrawal of the billet are outlined. (17 references).—P. M. C.

Effect of Nitrogen on the Solidity of Medium-carbon and Low-alloy Steel Castings. J. H. Fuqua. (*Amer. Inst. Min. Met. Eng.* 1955, *Preprint*). During studies of the effects of nitrogen content on the mechanical properties of medium-carbon and low-alloy steels, a peculiar type of skin porosity has been noted in green-sand castings when soluble nitrogen exceeded 0·01%. An addition of 3–4 lb. of 50% TiSi is sufficient to suppress the reaction, the mechanism of which is discussed.—G. F.

Gas and Inclusions in Cast Steels from Open Hearth Furnaces. (*Génie Civil*, 1955, **132**, Dec. 15, 470–472). Carbon oxides and hydrogen, and solid sulphides are considered. The deoxidation of steel is reviewed and the fusion diagram for the Fe-FeS system is sketched.

On the Course of Deoxidation and the Formation of Inclusions. W. Koch. (*Rudarsko-Metalurški Zbornik*, 1954, No. 1, 3–26). [German Summary]. A review of the behaviour of oxide particles in liquid steel and the conditions under which they become suspended is given. The effects of deoxidants is then considered.

Effect of Medium and High-carbon Ferrochromium in the Charge on Stainless Melting Practice. L. G. Cotton Jr. (*Amer. Inst. Min. Met. Eng.*, 1955, *Preprint*). At Duquesne works of United States Steel Corp., medium-carbon or high-carbon ferrochromium is substituted for some of the chromium stainless scrap in all 12–27% Cr stainless steel heats. The melting practice is summarised and compared with that employed in all-scrap charges, with particular attention given to chromium recovery.—G. F.

FOUNDRY PRACTICE

Proceedings of Missouri Valley Regional Foundry Conference 1955. (*Bull. School Mines Met. Univ. Missouri*, 1956, No. 91). **New Horizons in Foundry Progress,** H. J. Heine, (1–14). An introductory address reviewing recent developments. **Progress in Shell Moulding and Shell Core,** W. J. White (15–24). A general account of practice, with discussion. **Practical Approach to Quality Control in the Grey Iron Foundry,** C. F. Walton (24–34). **Practical Mechanisation for Small Foundries,** C. V. Nass (34–39). **Heat Treatment of Grey Iron Castings to Develop Maximum Properties,** C. R. Austin and W. W. Kerlin, (39–44). A short account of theoretical and practical considerations with discussion. **Steel Castings *v.* Forgings,** J. B. Caine, (45). (Abstract only).

New Zealand Foundry Practice. R. T. Young and L. H. Davenport. (*Castings*, 1955, **1**, Oct., 38–42 ; Nov., 29, 31, 33, 35–38 ; Dec., 19, 21, 23, 25–28, 1956, **2**, Jan., 15, 17, 19 ; Feb., 17, 19, 21 ; March, 13–14,; April, 3–5). Current New Zealand foundry practice is considered with reference to moulding sands, the grades and mechanical properties of cast iron, cupola furnace operation and the desulphurisation of cupola metal.—B. C. W.

An Introduction to Shell Moulding. W. A. Cleary. (*Australian Inst. Metals : Australasian Eng.*, 1955, Nov. 7, 63–68). The history and development of the relatively new casting process of shell moulding are outlined and the fundamentals of the process described. Dimensional accuracy is discussed, and the relationship between shell moulding and other casting processes. (17 references).—P. M. C.

Production Standards and Their Place in the Foundry Industry. S. D. Martin. (*Trans. Amer. Found. Soc.*, 1955, **63**, 317–324).

Risering of Nodular Iron. II—Effect of Silicon Content on Feeding Distance. R. C. Shnay and S. L. Gertsman. (*Trans. Amer. Found. Soc.*, 1955, **63,** 632–637). The feeding distances for ¼, 1 and 1½ in. thick semi-circular plates were determined for nodular irons with different silicon contents. Variation from 2·57 to 3·13% Si did not appreciably affect the feeding distance of hypereutectic nodular irons but hypoeutectic nodular irons had a shorter feeding distance than the hypereutectic irons.—B. C. W.

Selection of the most Economical Form and Calculation of Dimensions of Open Risers for Various Types of Steel Castings. G. Kniaginin. (*Prezeglad Odlewnictwa*, 1955, **5,** (7–8), 202–209). [In Polish]. A comparison of results obtained when using various methods of calculating risers is given.

A Practical Method of Using Hot-Top Risers in Steel Casting. G. Petzold, W. Lehmann and R. Richter. (*Giessereitechn.*, 1955, **1,** Dec., 234–239). A new method, based on the CO_2 process of constructing hot-top risers is described and illustrated. Practical results are reported. Comparative tables demonstrate liquid steel economies effected. A formula that has been found useful in casting practice is given.—L. J. L.

What Happens When a Core is Baked. C. E. Schubert. (*Foundry*, 1955, **83,** Nov., 128–130). Experiments on the baking of cores are described and show that silica sand cores containing core oils reach a temperature above that of the furnace in which they are being baked. Similar cores heated in nitrogen had little or no strength, indicating that polymerization of the core oil does not occur on heating and that the strength of the core depends on the ability of the oil to oxidize. Cores made with a phenolic resin binder and heated in nitrogen had a similar strength to those treated in oxygen.

Cores and Moulds by the CO_2 Process. A. Talbot. (*Found. Trade J.*, 1955, **98,** May 26, 559–568). The change over in a jobbing foundry from conventional coremaking practice to the sole use of the carbon dioxide process is described. The present coremaking practice is outlined and the relative costs of this and the conventional oil sand method are compared. The application of the process to moulds is briefly referred to.

Carbon-dioxide Process. D. V. Atterton. (*Found. Trade J.*, 1955, **98,** May 5, 479–482; May 12, 505–514). The historical development, advantages and limitations of the carbon dioxide process for hardening moulds and cores are outlined and results are given to show the effect of hardening on the compressive strength and on the other properties of different sands. Methods of introducing the gas into cores and moulds are considered in detail and the use of mechanical methods is described. The quality of surface finish and the degree of collapsibility obtained with the carbon dioxide processed sand is discussed for both ferrous and non-ferrous alloys.

Moulding an Exhaust Manifold. (*Fonderie*, 1955, July 4611–4616). A method for moulding and coring an exhaust manifold is described in detail.—B. C. W.

Precision Casting Methods. C. E. Gustafsson. (*Gjuteriet*, 1955, **45,** Dec., 178–180). [In Swedish]. A review of progress made deals with the principles of the lost-wax method, the manufacture of wax patterns and the associated moulds, pouring procedures, and the use of frozen mercury patterns.

Possibilities of Precision Casting. Metallurgical and Technological Aspects and its Advantages. Y. Deschamps. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1955, (4), 12–24). After stating the principles of lost wax casting, it is compared with ordinary casting, and the scope of the method is surveyed. Some practical details are given, with rules that must be observed when designing items to be cast by this method. Dimensional tolerances, surface obtained, suitable metals, advantages, and economic considerations are discussed.

Investment Casting Gets Nod as Cost Saver for Parts. J. B. Price. (*Western Metals*, 1955, **13,** May, 49–51). A brief account of the principles of investment casting is given, and the advantages of the process for producing intricate parts up to 7 in. maximum dimension to close tolerances are discussed.—P. M. C.

New Centrifugal Process Uses Sand-Resin Lining. E. Bremer. (*Foundry*, 1955, **83,** Aug., 90–93). A new centrifugal casting process for producing cast iron pressure pipes is described. The flask is a perforated steel tube with a centrifugally placed thin sand-resin lining. The sand-resin lining prevents chilling of the metal and gives a fine grey iron structure, but the rate of solidification is considerably increased above that observed with a conventional sand lining.—B. C. W.

Recent Developments in British Foundries With Special Emphasis on Shell Moulding and Shell Core Making. A. S. Beech. (*Castings*, 1955, **1,** Dec., 9, 11, 13, 15–16; 1956, **2,** Jan., 7, 9, 11, 13–14). Recent British developments in equipment for sand preparation, moulding, and core blowing are described.—B. C. W.

New Developments in Shell Moulding. V. di Sambuy. (*Fonderia Ital.*, 1955, **4,** Oct., 483–484). [In Italian]. The substantial strides made by shell moulding techniques in the course of the last few years are described. Reference is made to the Ford Motor Company compaction moulding process.—M. D. J. B.

How the Shell Mould Process is Applied in Industry. H. G. Sieggreen. (*Gen. Motors Eng. J.*, 1955, **2,** Jan–Feb., 16–21). An account is given of the shell mould process for producing castings, and a number of illustrations are given of complex parts already being produced using this process and the advantages to be obtained.—E. A. C.

Mechanised Foundry Colloquium on the Control of Grey Cast Iron Castings. (*Usine Nouvelle*, 1955, **11,** Dec. 8, 18–19; Dec. 15, 30–31; Dec. 29, 25–30; 1956, **12,** Jan. 5, 87–91). After the opening address, a paper on the relationship between mechanical engineers and founders is presented. The next two papers are on control of castings from the point of view of the user and of the founder. Labelling of products is then considered. General discussion includes mention of some results, control and testing, reduction of the number of rejects, means of obtaining qualified personnel, and improvement of labelled products, with definite indication of quality. A general summing up is followed by the closing address.

Specialisation of Quality in a Medium-sized French Foundry. (*Fonderie*, 1955, July, 4605–4610). A description is given of the foundries of the Société Mancelle de Fonderie.—B. C. W.

Chevrolet's Tonawanda Foundry. (*Foundry*, 1955, **83,** Sept., 112–142). A detailed description is given of the coremaking, moulding, melting, cleaning, and general foundry facilities at the new foundry of the Chevrolet Motor Division of General Motors Corp. at Tonawanda, N.Y.—B. C. W.

Design Aspects of Foundry Buildings. U. Lindahl. (*Gjuteriet*, 1956, **46,** Feb., 13–15). [In Swedish]. Some hints are given on points to be observed when rebuilding old foundries, together with views on the layout of new buildings. Construction and design of roofs, walls, floors, and lifting tackle are discussed.—G. G. K.

Influence of Core Making Materials on Development of Hot Tears. C. H. Wyman. (*Trans. Amer. Found. Soc.*, 1955, **63,** 203–208). The results are presented of a co-operative investigation into the reproducibility of data on hot-tearing obtained with a selected test casting made with standard cores. The relationships between the length of the hot tears and core density, pouring rate, pouring temperature, and core properties are discussed.

Metallurgical Examination of Hot Tears in Steel Castings. II. L. L. Clark. (*Trans. Amer. Found. Soc.*, 1955, **63,** 208–216). The data obtained in a co-operative investigation into hot tearing are discussed in an attempt to determine the factors responsible for producing hot tears. There appeared to be no correlation between the incidence of hot tearing and pouring temperature, pouring rate, microstructure, or inclusion type but there was evidence that deoxidation practice had a significant effect. Of seventeen castings poured from heats which were not deoxidized with aluminium only one showed a hot tear, but of 48 similar castings poured from heats to which aluminium had been added, 29 showed hot tears.—B. C. W.

Theory, Economics and Practical Application of Exothermic Materials. D. V. Atterton and C. Edmonds. (*Castings*, 1955, **1,** Sept., 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 25). The problem of feeding castings is discussed and the use of Thermit mixtures and mouldable exothermic material is considered in detail. The advantages and disadvantages of each metal are reviewed and the relative costs are calculated for several castings. The preparation of exothermic sleeves is described and their application to production castings is illustrated by reference to practical examples in grey iron, manganese bronze, and steel.—B. C. W.

Hot Strength of Clay-Bonded Sands. W. B. Parkes. (*Foundry*, 1955, **83,** Dec., 113–119). A test is described in which the compressive stress-strain curve of a specimen of foundry sand is determined after the specimen has been rapidly heated (>5°C/sec) to the required temperature.

The hot strength of a rapidly heated sand was found to approximate to the dry strength at room temperature which does not agree with the results of conventional hot strength tests in which the specimen is placed in a hot furnace and allowed to reach a uniform temperature before testing. It is concluded that the results obtained in the latter test do not represent the properties of the sand on the face of a mould during pouring. The effects of wood flour, sea coal, and organic binders on hot strength are discussed.—B. C. W.

Moulding Sand for Castings of Light Section. (*Fonderie*, 1955, Dec., 4837–4840). The requirements of moulding sands for thin castings are discussed and recommendations are made concerning the choice and preparation of suitable sands.—B. C. W.

Clay as a Binder in Synthetic Foundry Mixtures. C. Pelham. (*Rudarsko-Metalurški Zbornik*, 1954, No. 3–4, 259–273). Montmorillonite, kaolinite and micaceous clays are discussed with reference to composition and structure and localities are given. A table of optimum binder percentage is finally given.

The Drying of New Sand. (*Fonderie*, 1955, Oct., 4735–4745). The various methods available for drying and cooling silica sands are described in detail together with the methods for drying, grinding and sieving clay sands.—B. C. W.

Risering of Steel Castings—Development, Preparatory Study, Examples of Applications. M. Josset. (*Fonderie*, 1955, Aug., 4641–4650). The development and application of gravity and atmospheric risers is described and illustrated. The importance of a careful study of each particular casting before deciding on the risers to be used is emphasized. The risering of two production castings is then described in detail.

Carbon Dioxide in Moulding Sand produces High-strength Moulds. W. Magers. (*Giesserei-praxis*, 1953, **71**, 418).

Production of Foundry Cores by the Carbon Dioxide Process, and Necessary Equipment. W. Saubermann. (*Giesserei-praxis*, 1955, **73**, 29–32, 49–51).

Drying of Foundry Sand Moulds using Carbon Dioxide. S. I. Sysoev. (*Liteinoe Proizvodstvo*, 1952, **3**, 5). An account is given of a silicate-bound sand process which eliminates drying ovens.

Small Steel Foundry Produces Specialty Castings. E. Bremer. (*Foundry*, 1955, **83**, Dec., 94–97). The lay-out, equipment and foundry practice at the Waunakee Alloy Casting Corp., Waunakee, Wis., is briefly described.—B. C. W.

The Casting of Half a Face Plate for a Roundabout Engine. N. I. Averbuch and F. W. Miroschnitschenko. (*Giessereitechn.*, 1955, **1**, Aug., 147–148 : *Foundry Techn.* (Moscow), 1954, (8), 24–26). The casting, in two halves, of a 10 m roundabout engine face plate weighing 50 tons is described and illustrated.

Cylinder Liner Production : The Procedure Employed by Sheepbridge Stokes Ltd. to Ensure High Quality. (*Automobile Eng.*, 1955, **45**, Nov., 461–466). A very detailed account with illustrations is given of cylinder liner production. The liners are centrifugally cast in a variety of highly alloyed irons. Plant layout, furnaces, casting machines, machining, and final inspection are all dealt with in detail.

Precision Casting in Industry. K. W. Heimann. (*Mét. Constr. Mécan.* 1955, **87**, Nov., 875–885). The Croning, Lost Wax and Shaw processes are considered. The essential characteristics, equipment required, type of casting made and advantages of each process are described.—B. G. B.

Hot Tearing of Castings. R. A. Dodd. (*Canada Dep. Mines Techn. Survey. Mines Branch*, 1955, *Report No.* PM184, pp. 1–47). A review with 67 references.

So You Are Going To Try Shell Moulding. J. G. Steinebach. (*Foundry*, 1955, **83**, Aug., 104–107). The practical problems facing a foundry which starts to operate the shell moulding process are briefly discussed.—B. C. W.

Shell Cores : Their Production and Application. R. Olson. (*Foundry*, 1955, **83**, Dec., 108–112) Experiences in the manufacture and use of shell cores at the Production Pattern and Foundry Co., Chicopee, Mass., are discussed.—B. C. W.

Place of Shell Moulding in the Foundry. B. H. C. Waters. (*Found. Trade J.*, 1955, **98**, June 2, 587–596). The equipment and techniques used in shell moulding are reviewed and a comparison is made between the relative advantages and disadvantages of the shell moulding process, conventional sand moulding, precision investment casting, the "D" process, and high-pressure moulding.—B. C. W.

The Development of the Shell Moulding Process at the Watertown Arsenal from 1951 to the End of 1954. J. F. Wallace and G. J. Snider. (*Fonderie*, 1955, Dec., 4801–4816). The equipment used, and techniques developed, at the Watertown Arsenal for the production of shell moulded castings are described in detail.—B. C. W.

Technological Properties of Shell Moulds. Z. Samsonowicz. (*Przeglad Odlewnictwa*, 1955, **5**, (7–8), 228–232. [In Polish]. Methods of making test specimens and the results of investigations on the dependence of strength and permeability of shell moulds on the proportion of resin, temperature and time of hardening are described.–V. G.

Concerning Foundry Defects. J. Pascal. (*Mét. Constr. Mécan.* 1955, **87**, Dec., 959–961 ; 1956, **88**, Jan., 15–19). The origin and elimination of defects in foundry casting are considered.—B. G. B.

VACUUM METALLURGY

Methods of Melting and Casting *in Vacuo* and Press Forging. (*Génie Civil*, 1955, **132**, June 1, 208–212). Post-war developments are briefly reviewed, and the two main uses are stated : treatment of reactive metals and alloys and refining of metals by volatilization. Problems arising in the processes are mentioned, and apparatus is indicated diagrammatically. Pumps and pumping conditions are discussed and notes on large ingots and their forging are added.

Vacuum Melting Furnaces—An Interim Report. F. Chesnut. (*Metal Progress*, 1955, **68**, Nov., 118–123). A short review is given of the development and present state of commercial vacuum melting furnaces for melting steel, molybdenum and titanium. A description of modern furnaces which can cast 1000 lb ingots is presented.—B. G. B.

European Vacuum Melting, History and Practice. H. H. Scholefield. (*Metal Treatment and Drop Forg.*, 1955, **22**, Apr., 141–147). A review of past achievements and present trends in vacuum melting of metals is made. Furnace designs, pumping equipment, and operational procedures are dealt with. (10 references).—P. M. C.

Study on the Degassing of Metals. O. Winkler. (*Rev. Mét.*, 1955, **52**, Dec., 934–942). The kinetics of the process are discussed, and the factors influencing the rate of attainment of equilibrium in vacuum systems. Apparatus is described and experiments on brass are shown to be in agreement with the theory.

Degassing of Molten Metals by Vacuum Treatment. O. Winkler. (*Vakuum-Technik*, 1954, **3**, 87–96). The work described is on copper, but steel degassing is discussed.

Graphite Formation on Steel Surfaces during Vacuum Heat-treatment. E. Z. Graifer and I. V. Salli. (*Doklady Akad. Nauk S.S.S.R.*, 1954, **97**, (4), 663–665). An account of experiments on the effects of cooling rate and silicon content is given.

Vacuum Metallurgy. Vacuum Metallurgy Symposium, Electrochemical Society, Oct., 1954. **The Bright Spark in the Metals Industry.** J. D. Nisbet. Introductory. **Arc Melting in High Vacuum.** P. C. Rossin. Discussion of factors in arc stability and control, and a qualitative analysis of thermal equilibria at cathode, arc column, anode, and mould–metal interface. **Vacuum Melting of High-alloy Materials.** H. R. Spendelow Jr., I. S. Servi, and G. A. Fritzlen. The reactions occurring during melting of Hastelloy R-235. **Impact Properties of Vacuum-melted Iron–Chromium Alloys.** J. L. Ham and F. L. Carr. **Vacuum-melted Zirconium and Alloys.** H. A. Saller, R. F. Dickerson, and E. L. Foster Jr. **Vacuum and Pressure Melting of Iron-base Alloys.** E. R. Morgan and D. N. Frey. A review of Ford Motor Co. practice. **The Design and Operations of an Induction and a Resistance Furnace for High Vacuum–High Temperature Applications.** R. F. Domagala and D. J. McPherson. Modifications of previously described furnaces are outlined. **A New Method for the Evaluation of High-Vacuum Furnaces and Heat-treating Atmospheres.** W. R. McMillan and E. A. Gulbransen. Polished iron strips are exposed to the furnace atmosphere and examined by electron micrography. **Theory and Performance Characteristics of a Kinney Mechanical Booster Vacuum Pump.** C. M. Van Atta and R. L. Sylvester. **Rotary Gas Ballast Pumps.** T. E. Burleigh Jr. and W. C. Frye. **The Economics of Vacuum Melting.** C. J. Crites. **Deoxidation of Vacuum-melted M252.** W. F. Moore and R. K. McKechnie. **Hydrogen Deoxidation of Vacuum-melted High-temperature Alloys.** R. L. Hadley and L. M. Bianchi. **The Applications of Vacuum Technology to Metallurgical Processes.** R. G. Ulrech. **Vacuum Heat-treating Techniques.** R. L. Hoff and A. M. Bounds. **Solid State Purification of Molybdenum by Induction**

Heating. F. C. Todd, J. E. Drennan, and W. W. Kleinschmidt. **Vacuum Degassing of Titanium.** C. B. Griffith and M. W. Mallett. **Determination of the Vapour Pressure of Metals and Alloys.** R. Speiser and J. W. Spretnak. A review of theory and accounts of practical methods. **Experiments on Vacuum Distillation of Nonferrous Metals and Alloys.** M. J. Spendlove. (Published by the Electrochemical Society Inc., 1955, pp. 213.)

REHEATING FURNACES AND SOAKING PITS

The Rotating Hearth Furnace in the Tube Industry. (*Mét. Constr. Mécan.*, 1955, **87,** Oct., 803–805). A short illustrated description of this type of furnace is given. The consumption of fuel oil is 20–26 tons/h corresponding to 480 k.cals/ton metal heated to 1250° C.—B. G. B.

Industrial Furnaces. (*Report of Symposium of Amer. Soc. Mech. Engrs. and Inst. Mech. Engrs.*, 1955, *Boston, preprint*). **Gas as Source of Protective Atmosphere in Industrial Furnaces.** E. J. Funk (3–5). The use of natural gas is outlined. **The Status of Combustion in Industrial Furnaces.** J. J. Turin and J. Huebler. (6–8). A review with notes on soaking pits, forging furnaces and the heating of strips is presented. **Instruments as Applied to Improvement in Steel Furnaces.** J. W. Percy. (9–11). A brief diagrammatic outline of applications. **High-temperature Gaseous Jets as applied to some Manufacturing Processes.** J. B. Henwood. (18–25). Surface hardening, strip heating, and continuous strip heating are mentioned. **Combustion and Heat-transfer in the Open Hearth Furnace.** S. W. Pearson, J. H. Chesters and M. W. Thring. (26–34). An introduction to a quantitative theory of the O.H. furnace with tables and diagrams, and an account of practical trials is given on the general basis of heat evolution, flow, and balance. **Oil Burners for Open-hearth Furnaces.** M. J. McInerney, G. R. Mattocks and M. P. Newby. (35–42). A comprehensive account is given, fully illustrated. **Advances in Cupola Combustion.** H. Jungbluth and K. Roesch. (43–57). The theory of the cold-blast cupola is developed with discussion of oxygen-enriched blast and hot blast, and the waste gases are then discussed with a section on blast temperature control. The advantages of hot blast working are considered and set off against installation costs. **Combustion and Thermal Transfer in Continuous Reheating Furnaces.** H. Southern, F. A. Gray and D. Smith. (65–70). Heat transfer calculations are presented with an account of experimental furnace results.

Modern Reheating and Heat-Treatment Furnace Practice : Economic Operation of Fuel-consuming Systems. M. W. Thring. (*Metal Treatment and Drop Forg.*, 1955, **22,** Dec., 507–514). The problems of the efficient burning of fuels in heating furnaces and their economic operation are discussed. Special reference is made to the principles of oil firing, and to methods of improving simple heating systems. (13 references).—P. M. C.

Increased Heating Rates for Steel Ingots. P. M. Cook and J. D. Stringer. (*J. Iron Steel Inst.*, 1956, **184,** Nov., 309–315). [This issue].

New Non-Scaling Gas-Fired Forge Furnace. (*Metal Treatment and Drop Forge*, 1955, **22,** July, 306–308). The " Equiverse " heating system developed by The Incandescent Heat Co. Ltd. is described. The design and performance of a new billet heating furnace are reported. The new system incorporates a reversing regenerative technique which preheats the combustion air to a temperature above 1000° C and thereby allows an exceptionally high proportion of CO in the furnace gases (about 14%). Very rapid scale-free heating of steel billets is obtained with good fuel economy.—P. M. C.

New Electric Element for Heat Treatment Furnaces. (*Steel Processing*, 1955, **41,** Sept., 583, 584). Brief details are given of a newly developed furnace heating element by the Lindberg Engineering Co., U.S.A. The element, named Corrtherm, is in the form of corrugated sheets of nickel chromium. These sheets cover almost the whole furnace wall and operate at a low voltage. Their large surface area allows lower surface temperatures then heretofore and consequently longer element life.—P. M. C.

Rapid Heating of Forging Die Blocks. (*Steel Processing*, 1955, **41,** Sept., 576–578). A description is given of the performance of a new gas-fired furnace built by the Selas Corp. for the Heppenstall Company, U.S.A. Fast heating is employed ; a 20-ton load of die blocks of up to 24 in. section is heated for forging in 3 to 4 hours as against the previous 20 to 30 hour heating cycle.—P. M. C.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Design of Special Atmosphere Furnaces and their Application to Heat-Treatment of Metals. I. Jenkins. (*Metal Treatment and Drop Forg.*, 1955, **22,** Sept., 369–374 ; Oct., 415–420). The various types of specially prepared furnace atmospheres and their various applications in heat treatment are reviewed. Some general aspects of electric furnace design are then discussed, and several examples of batch and continuous type electric furnaces are described and illustrated.—P. M. C.

Heat Treating Ductile Iron. R. E. Savage. (*Steel*, 1955, **137,** Nov. 21, 108–109 ; Nov. 28, 109–115). The theory and practice of heat treating ductile iron are described. Treatments are given for stress relief and softening, hardening and surface hardening ; a table summarizes results and applications.—D. L. C. P.

Heat Treatment of Cast Steels. (*Fonderie*, 1955, May, 4529–4533 ; June, 4573–4575). The principles on which the heat treatment of cast steels is based are outlined. The aspects covered include homogenisation of the cast structure, modification of the as-cast microstructure and quenching tempering.—B. C. W.

Heat-Treatment in a Region of Varying Temperature, Particularly During an Increase in Temperature. R. Mitsche. (*Härterei-Tech. Mitt.*, 1955, **9,** Dec., 9–23). The hardness of tool steels can be increased by treatment below 250° C after quenching but prior to tempering. The transformation of structural steels can be influenced by means of a pre-transformation treatment. (16 references).—R. P.

Continuous Heat Treatment for Automatic Production. W. J. Behrens. (*Steel Processing*, 1955, **41,** Aug., 525–529). The author suggests that the development of continuous heat treatment furnaces is moving the heat treatment operation, on small components, from the old conventional treatment shop into the automatic production line. This view is illustrated by reference to the plant installations at the Marion Manufacturing Division of Dana Corp., U.S.A. Integrated annealing, hardening and tempering, mechanical cleaning, grinding and other operations are used in the manufacture of automotive parts and bearing races.—P. M. C.

The Development of Automation in Heat Treatment. E. G. de Coriolis. (*Indust. Heating*, 1955, **22,** Oct., 1974–1978, 2178). Methods of heat treatment of small parts in continuous furnaces provided with controlled atmospheres and operated in conjunction with washing and machining units are described.—A. D. H.

Automatic Furnace Line in Highly Versatile Forge Shop. (*Indust. Heating*, 1955, **22,** Nov., 2244–2252). A completely automatic gas fired pusher furnace for hardening, a quench tank and a high temperature tempering furnace for forgings weighing 2½–75 lb are described.—A. D. H.

Salt-Bath Tempering for Constructional Steel. B. Finnern. (*Das Industrieblatt*, 1955, Sept., 458–468 ; *Usine Nouvelle*, 1956, **12,** Mar. 29, 86–89). The two methods of tempering, namely cooling in oil, water or aqueous solution, and in a molten salt bath are compared. The latter provides a controllable cooling medium, where cooling takes place by conduction and convection instead of by vaporisation, which can be very localised. The effect of water content of the salt bath on rate of cooling is examined. Deformations occurring during tempering and the need for controlled cooling are discussed.—T. E. D.

A Study on Heat-Treatment of High C-Cr Magnet Steel. Relation between Annealing Temperature and its Hardening Quality and Magnetic Properties. W. Ota. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** June, 305–307). [In Japanese]. In magnet steel containing 1% of carbon and 3·6% of chromium, the minimum hardness after annealing is shown at the Ac_1 point ; this decreases with rise of annealing temperature to Ac_1, but then rises again. The size of spheroidal carbide shows similar trends. Hardening is eased as the annealing temperature is lowered. The effect of annealing temperature on magnetic properties is similar to that on hardness.—K. E. J.

Low-temperature Treatment of Cr-W-Mn Tool Steel. L. I. Gardina. (*Vestnik Mashinostroenniya*, 1953, **33,** (11). 54–55). Tempered specimens were cooled in liquid oxygen-

chilled petroleum. Martensite transformation was observed and studied by magnetic measurements.

Metallographic Study of Tempering of Quenched High-carbon Steel. A. P. Gulyaev and M. P. Zel'bet. (*Izvest. Akad Nauk, S.S.S.R., Otdelenie Tekn. Nauk.*, 1954, March, 83–87). Investigations on large-grain steel specimens are described in which metallographic changes are more obvious. The appearances are correlated with X-ray data.

Materials Handling at High Temperature, Mechanized with Cast High Alloy Heat-treating Components. (*Indust. Heating*, 1955, **22,** Oct., 2047–2060). The application of steels containing Cr 13–28, Ni 11–37% in furnace conveyors and construction at the works of International Harvester Co., Chicago, are described.—A. D. H.

Heat-treatment Installation at Smith-Clayton Forge Ltd. (*Metal Treatment and Drop Forg.*, 1955, **22,** Jan., 15–17). A new automatic hardening and tempering unit, installed by British Furnaces Ltd., is described. The installation consists of a town's gas fired hardening furnace, oil quench tank with cooling and circulating system, and a towns gas-fired tempering furnace, with a return track for the work trays. Output, of drop forged crankshafts, is 22 cwt per hour.—P. M. C.

New Continuous Gas-Carburizing Furnace at the Works of the Ford Motor Co. Ltd., Dagenham. (*Metal Treatment and Drop Forg.*, 1955, **22,** Aug., 331–335). A description is given of a new three-track gas-carburizing furnace built by the Electric Resistance Furnace Co. Ltd. The furnace has an hourly output of 550 lb when operating to effective case depths of about 0·060 in. on auto-transmission components. Gas-fired radiant tubes are used as the heating medium, and the carburising atmosphere is generated in an EFCO endothermic town's gas generator. The carrier gas is enriched with about 1% of butane.—P. M. C.

Gas Carburizing—A Controlled Production Tool. F. E. Russ. (*Steel Processing*, 1955, **41,** June, 383–390). The mechanism of gas carburization and the choice of atmosphere are briefly reviewed. Various types of equipment including continuous, rotary, batch type and vertical pit furnaces are described and illustrated.—P. M. C.

Proper Stock Removal in Finishing Case Hardened Parts. D. F. Hammer. (*Steel Processing*, 1955, **41,** Aug., 489–494). The author discusses the various methods of case hardening with particular reference to methods in which the chemical composition of the surface layers is changed (chromizing, nitriding, siliconizing, carburizing). The penetration of hardness as a function of change in composition is then considered, and the removal of surface material by subsequent machinery is discussed in relation to the depth and changing hardness of a hardened case.—P. M. C.

Fundamental Considerations Governing the Hardening of Cast Iron. R. Jonck. (*Härterei-Tech. Mitt*, 1955, **8,** Dec., 19–34). The fundamental principles of hardening are discussed in relation to the properties and structures obtainable. A low temperature is recommended for hardening cast iron. A decarburizing atmosphere during hardening is to be avoided because it may lead to structural changes, starting at the surface. Cracks may develop during quenching in water if the hardening-temperature is too high. Oil quenching (or other mild media) are recommended when the hardness aimed at is not too great.—R. P.

Flame Hardened Ductile Irons. C. E. Ernst, R. V. Adair, and G. L. Cox. (*Mat. Methods*, 1955, **42,** Nov., 106–109). A procedure for successfully flame hardening the surfaces of sprockets, gears, rolls and similar components made from ductile iron is described. Surface hardness up to Rockwell C64 with excellent wear resistance is claimed. To obtain this result the iron must be mostly pearlitic and stress relieved before heating. (2 references).—P. M. C.

Studies on the Hardenability of Boron Steel. I. On the Boron Treatment of Commercial Carbon Steel. T. Mitsuhashi and K. Tsuya. (*Nippon Kinzoku Gakkai-Si*, 1954, **18,** Feb., 94–98). [In Japanese]. The influence of boron on 0·4% C steel is discussed in relation to isothermal transformation, austenitic grain size and Jominy hardenability.—K. E. J.

Selective Surface Hardening. J. L. Harris. (*Australian Inst. Metals : Australasian Eng.*, 1955, Oct. 7, 45–52). The author describes briefly a number of methods of hardening selected surfaces and then deals in some detail with flame hardening. The four methods of flame hardening, spot, progressive, spin and progressive-spin are described, and the equipment used, the results obtainable and some examples of the type of work done on modern machinery are illustrated. (7 references).—P. M. C.

Which Method for High Speed Surface Hardening ? W. S. Hyler and H. J. Grover. (*Mat. Methods*, 1955, **42,** Aug., 103–105). Induction and direct gas heating methods for surface hardening have been examined as to their relative merits and limitations in tests conducted by the Battelle Memorial Institute. The results of this work suggest that the choice between the methods is chiefly an economic one, gas heating being superior in this respect. (6 references).

Investigation of the Temperature of Sparks in Metal Hardening Apparatus. A. N. Lyulichev and L. S. Palatnik. (*Izvest. Akad. Nauk S.S.S.R. Seriya Fiz.*, 1955, **19,** (1), 66–67). An empirical expression is given in terms of capacity.

Automatic Crankshaft Hardening Machine : A New Application of the Peddinghaus Oxy-Town Gas Process. (*Automobile Eng.*, 1955, **45,** Sept., 394–396). A full description with illustrations is given of the principles and method of operation of two new Peddinghaus flame hardening machines recently installed at the Lincoln Works of Ruston and Hornsby Ltd. The machines burn a mixture of 37½% oxygen, 62½% town gas by volume, one dealing with 4-throw crankshafts, the other with 6-throw 7-journal shafts. The new machines are designed to harden journals and pins simultaneously and automatically.—P. M. C.

Retention of Hardness of Medium-Carbon Steel after Electrospark Hard-facing. V. N. Tsvibel, B. A. Krupitskii and L. N. Balakina. (*Vestnik Mashinostroenniya*, 1953, **33,** 75–76). Measurements were made over the range 400–1300°F.

A New Technique for the Surface Hardening of Crankshafts : German Induction-Heating Units in Operation in the U.K. T. Bishop. (*Metal Treatment and Drop Forg.*, 1955, **22,** July, 295–298). New induction-heating equipments, by AEG-Elotherm, for hardening the journals or pins of crankshafts are now in operation at the works of Ambrose Shardlow & Co. Ltd. of Sheffield and of the Ford Motor Co. Ltd. at Dagenham. Open, non-contacting type heaters are employed, in conjunction with an indexing holder which rotates each journal into a quench tank for hardening after heating.—P. M. C.

Study of the Behaviour of Surface Layers by X-Ray Stress Measurements and Measurement of Elastic Constants in 0·43% C Steel. H. Hendus and C. Wagner. (*Rev. Mét.* 1955, **52,** Dec., 982–994). Elasticity and internal stress measurements are recorded on 0·16, 0·43, and 0·75% C steels using Co, Cr, and Mo X-radiations. Elastic constants for 0·43% C steel are determined.

Effect of Initial Heat-Treatment on the Response of a Steel to Induction Hardening. H. Allsop. (*Metal Treatment and Drop Forg.*, 1955, **22,** Feb., 47–50, 53). Tests are described which were undertaken to assess the effect of pre-treatment on the response to Tocco induction hardening of a 0·47% C, 0·94% Cr, 0·24% Ni, 0·26% Mo steel. 1¼ in. diameter bars were oil quenched, and tempered at 550, 600, 650, and 700° C ; other pieces were annealed at 850° C. Case hardness and depth after subsequent induction hardening deteriorated as the tempering temperature was increased. Poorest results were obtained from the annealed samples. These results indicate that a fine carbide particle size is desirable, owing to its effect on rate of resolution during induction heating.

The Nitriding of Iron Alloys and its Influence on Wear-Resistance. J. Müller. (*Härterei, Tech. Mitt*, 1955, **9,** Dec., 25–44). The nitriding of iron and steel is discussed with particular reference to the influence of hardness and of nitrogen on wear-resistance. The uses of nitrided steels are summarized.—R. P.

Studies on Quenching Media. VII. The Cooling Ability of Mineral Oil. M. Tagaya and I. Tamura. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** May, 217–220). [In Japanese]. In oils of the same series, those of higher mol. wt have higher characteristic temperature and temperature of commencement of convection. In oils of approximately equal mol. wt, non-paraffin oils show similar tendencies together with higher cooling velocities in the convection stage. The properties are related to physical properties of the oils.—K. E. J.

Study on the Austempering for Structural Low-Alloy Steels. II. The Tempering Temperature-Hardness Relation and Tensile Properties after Austempering. H. Hotta and I. Tatsukawa. (*Nippon Kinzoku Gakkai-Si*, 1954, **18,** Feb., 91–94). [In Japanese]. In tempering austempered Ni-Cr and Ni-Cr-Mo steels at the intermediate region, the initial

hardness was preserved below the austempering temperature, and a little hardening at 350° was caused by decomposition of retained austenite. The tensile properties of specimens fully austempered at the intermediate region were lower than those of specimens oil-hardened and tempered.—K. E. J.

FORGING, STAMPING, DRAWING, AND PRESSING

Manufacture of Drop Forgings in the Motor Industry. (*Metal Treatment and Drop Forg.*, 1955, **22,** July, 299–305; Aug., 351–357). The extent and activities of the drop forge of the Austin Motor Co. Ltd., at Longbridge are described. A detailed description of the various divisions is given, viz. die design and manufacture, material supply, the various forms of forging plant, together with the main ancillaries, heat treatment, cleaning, inspection and metallurgical control. A review of the manufacturing stages of a number of the drop-forged components for the Austin A30 car is given.

Manufacture of Small Drop Forgings : Forging Practice at Arthur Robinson & Sons Ltd., Willenhall. K. G. Lewis. (*Metal Treatment and Drop Forg.*, 1955, **22,** Jan., 21–28; Feb., 61–64). The forging practice for products within the range ½ oz to 4 lb is described. Such forgings require special attention both in respect of design of dies and the techniques used. Plant layout, types of product, die design and sinking, control of forging "fibre," and some special examples with stamped out centres and heavy metal displacement are dealt with, according to the procedures at A. Robinson & Sons' Forge. (3 references).—P. M. C.

High Powered Induction Heating in Shell Forging. H. J. Landsman and A. T. Lattauzeo. (*Steel Processing*, 1955, **41,** July, 453–457). A description with illustrations is given of induction heating equipment installed at the U.S. Hoffman Machinery Co. Ordnance Plant for heating the nose ends of 8 in. and 155 mm artillery shells prior to forging of the nose. The installation includes four 1250 kW 960 cycle motor generator sets, one set of motor generator and feeder control, fourteen 960 cycle power stations, twenty-eight heating coils, and automatic handling equipment for feeding the shells.

Axle Shaft Manufacture : An Electric Upsetting and Press Forging Production Unit. (*Automobile Eng.*, 1955, **45,** Dec., 570–572). The production of axle shafts from 1 in. diameter alloy steel bar stock at the Newton Works of Garringtons Ltd., is described. Two Hasenclever semi-automatic electric upsetting machines are used to produce a bulbous end on the shaft; this end is then die forged under an 800 tons friction screw press into the required disc shape.—P. M. C.

Internal Stresses in some Types of Forging. C. Sykes. (*Steel Processing*, 1954, **40,** Feb., 101–107, 118, 120; Mar., 168–173, 186). Equations are quoted for the theoretical stresses set up in an infinite cylinder during cooling. Cooling rates at 600° C to cause residual stresses of 2, 5 and 10 tons/in² in diameters up to 80 in. are tabulated. The γ–α transformation during cooling from forging temperature is then considered with particular reference to the TTT-curves for a plain carbon and a Cr–Mo steel. The calculation of times required for the centres of large masses to transform is discussed and the effect on final residual stress of relaxation at tempering temperatures, during cooling from 600° to 350° C and on cooling in free air is outlined. The application of the above in the development of heat-treating and stress-relieving cycles for large forgings is described. (12 references).—P. M. C.

The Design of Simple Dies for Bending Operations. W. M. Halliday. (*Steel Processing*, 1955, **41,** May, 311–314, 331). Difficulties often encountered in the design of bending dies for articles which have an apparently straightforward shape are discussed by considering a common circular cleat (clip) made from flat steel strip of 14 gauge material ¾ in. wide. The design and action of two simple dies eventually developed to produce this clip are dealt with in detail.—P. M. C.

Vehicle Spring Manufacture ; Production Methods at the Stocksbridge Works of Samuel Fox and Co. Ltd. (*Automobile Eng.*, 1955, **45,** Sept., 387–393). Full details with illustrations are given of the production of both laminated and helical springs for road vehicles. Silico-manganese steel is used, and heat treated to a Brinell hardness in the range 375–444.

How to Form Stainless Steel. (*Steel*, 1955, **137,** Nov. 14, 112–115). Characteristics of forming methods usable for stainless steels are given and summarized in a table.—D. L. C. P.

Tolerances in Metal Stampings. F. Strasser. (*Steel Processing*, 1955, **41,** Aug., 505–508). The author discusses the factors which should be taken into account when establishing tolerances for sheet metal stampings. The influence of component and die design on the accuracy attainable is dealt with.—P. M. C.

Stamping in Motor Car Construction. M. Jentet. (*Mét. Constr. Mécan.*, 1955, **87,** June, 501–508; July, 585–589; Sept., 701–705; Oct., 785–791; Nov., 899–903; Dec., 963–971). Examples of the machines used for the pressing and stamping of sheet metal into components for motor car bodies and the techniques used are explained. The design of the moulds and their construction are described. The organization of plants for the mass production of motor car bodies is discussed and illustrations of existing plants and equipment are given. The metallurgical properties of the materials used in motor car bodies are considered.—B. G. B.

Coined—Embossed Sheet Metals. M. W. Riley. (*Mat. Methods*, 1955, **42,** Dec., 94–97). Sheet metals, with a variety of patterns coined or embossed on the surfaces by rolling between engraved rolls, are now being produced on a continuous basis at speeds up to 1000 ft per min and in widths up to 50 inches. Whilst the main application of such materials is for decorative purposes, mechanical properties are improved by embossing. Methods of fabrication are discussed.—P. M. C.

Service Life of Press Parts Increased as High as 18 Times with Ductile Cast Iron. (*INCO Magazine*, 1955, **26,** Oct., 35–36). Crankshaft, backshaft, gears and dies for 100-ton presses are illustrated.

On the Plug Drawing of Steel Tubes. S. Yazawa. (*J. Mech. Lab. Japan*, 1955, **9,** Sept., 199–206). An equation for the drawing force is derived in terms of the angle, reduction in wall thickness, ratio of original wall thickness to tube diameter, and coefficient of friction. Experiments carried out to verify theory, though limited in range, agreed well with equation for $\mu = 0{\cdot}05$.—J. G. W.

The Investigation of the Wire Drawing with Die Generated by Conical Section. T. Nishihara, M. Kakuzen and H. Nakamura. (*Tech. Rep. Eng. Res. Inst. Kyoto Univ.*, 1955, **5,** Aug., 75–115; Report No. 22). [In English]. Drawing stress is analysed theoretically, and experiments on measuring friction between the rod and the die wall, and for measuring stress, in carbon steel and other metals, are described. The effects of drawing conditions on mechanical properties are described. The shape of the die wall is the best factor for assessing die quality, and large radii of curvature give good mechanical properties.—K. E. J.

Wear of Diamond Wire-drawing Dies. L. Schultinck, H. L. Spier and A. J. van der Wagt. (*Draht*, German ed., 1955, **6,** Sept., 366–370). It is shown by reference to crystal structure, etching and spark experiments, that diamonds are anisotropic in terms of resistance to wear, and it is concluded that wear of a diamond die is likely to be axially symmetrical and least intense if the drawing hole is oriented normally to the octahedral surface.—J. G. W.

Wire Flattening. A. Ball. (*Caledonian Works, Halifax, Staff School, Second Award Paper*, 1955, pp. 1–20). Materials, machines, processes and theoretical considerations are described in detail, with an account of production planning and costing. Factors governing spread are set out and discussed, with notes on rolling heat, lubricant and load.

Weaving of Spring Steel Wire. A. Jasper. (*Draht*, 1955, **6,** Nov., 437–442). The construction of wire netting made of high-tensile wire and the designs of weaving machines are described.—J. G. W.

Reflections upon Transport in the Wire Industry. W. D. Broadbent. (*Caledonian Works, Halifax, Staff School, First Award Paper*, 1955, pp. 1–17). An account is given of organisation and administration, road versus rail, shipping, freight rates, and insurance, with practical and legal notes.

Hydraulic Accumulators in Heavy Industry. J. G. Frith. (*Inst. Mechanical Eng.*, 1955, Preprint, pp. 13).

ROLLING-MILL PRACTICE

Davy-United Plant at the Steel Company of Wales. (*Davy-United Engineering*, 1954, **1,** Jan., 13–20). A description is given of rolling equipment with plans and photographs.

Latent Resources of Rolled Metal. F. M. Kerdman. (*Stal'*, 1955, (4), 372–373). [In Russian]. Better utilization of rolled products is considered, some examples being given.

Determination of Power Required during Rolling, the Design of Mill Stands, and the Choice of Roll Diameter. K. Puppe. (*Stahl u. Eisen*, 1955, **75,** Oct. 20, 1401–1403). A new method of calculating power requirement is given. A quantity KE is defined such that the power required for rolling is given by KE. b.v., where b is the width of the bar and v is the rolling speed. KE is a function of material properties, bar dimensions and temperature, reduction, etc., and experiments are described from which characteristic curves were plotted enabling KE to be read off for any given rolling condition on the particular mill tested. Another quantity, DE, is defined such that the total roll load is given by DE.b.v. If P is the horizontal component of roll load, it can be calculated from P.v = KE.b.v. The total load is the resultant of D and P, and can be used to determine the proportions of the mill stand and rolls. It is claimed that the computation involved in existing methods of calculation has been such that it has led to reliance on empirical rules rather than exact reckoning, and that the new method facilitates calculation sufficiently to make it useful in practice.—A. C.

The Influence of Recent Rolling Mill Research on Mill Practice and Design. M. F. Dowding. (*Davy-United Engineering*, 1954, **1,** Jan., 2–5). The equations are given and their application discussed.

High Speed Rod Rolling at Continental Steel Corp. D. C. Horsman. (*Iron and Steel Eng.*, 1955, **32,** Dec., 53–59). This paper describes the machinery and equipment of a new high speed rod mill recently installed by Continental Steel Corp. The mill can produce a complete range of sizes from 7/32 up to 43/64 in. dia., and can be equipped to roll up to 1 in. dia. rounds. It has a capacity of 50 tons per hour.

Precision Contour Rolling Teams with Welding to Produce Steel Propellers. A. E. Felt. (*Steel Processing*, 1955, **41,** May, 305–309). The article describes and illustrates a method of fabricating hollow steel aircraft propeller blades developed by the A. O. Smith Corporation, U.S.A. The 16 various parts of the blade are produced from bar and plate stock by forging, contour rolling and forming, after which they are joined by 14 flash and one fusion welds. For further details of the precision forging and contour rolling see also *Steel Processing*, 1955, **41,** Sept., 571–574, 602.

The Precision Forge—Roll Process. A. E. Felt. (*Steel Processing*, 1955, **41,** Sept., 571–574, 602). The manufacture of parts, built up from components precision forged and/or contour rolled is described. A 9000 ton mechanical press with a 12-in. stroke is used to die forge parts to a high degree of accuracy, and other parts are made in a 1800-ton contour rolling mill. The tolerances achieved with these machines is discussed, and the fabrication of "built-up" assemblies is outlined. The technique is being used by the A. O. Smith Corp., U.S.A. For a description of the fabrication of hollow propeller blades by this process, see also *Steel Processing*, 1955, **41,** May, 305–309.—P. M. C.

Roll Formed Sheet Metal Parts. E. J. Vanderploeg. (*Mat. Methods*, 1955, **42,** Nov., 100–102). In the cold roll forming process, intricate shapes of uniform cross section are produced from sheet by feeding the material through successive pairs of rolls with gradually changing profiles. The author discusses design considerations, cost factors, and applications, and indicates the types of metal available in this form.

Modernization of 84-in. Plate Mill at Alan Wood Steel Co. T. H. Williams. (*Iron Steel Eng.*, 1955, **32,** Nov., 110–114). The layout of the old mill is described, the reasons for carrying out the modernization programme are discussed and details of the new layout and operating conditions are given.

A Continuous Strip Mill. T. Wimmer. (*Werk und Wir*, 1955, **3,** Nov.-Dec., 410–415; 1956, **4,** Feb., 57–63). An account of the planning, building, and putting into operation of the Hoesch Walzwerke A.-G. Hohenlimburg plant, with a history of the company and district. The articles are fully illustrated, partly in colour.

Electric Equipment for Reversing Hot Strip Mills. C. C. Thomas. (*Iron Steel Eng.*, 1955, **32,** Dec., 92–109). A detailed description is given of the unusual reversing hot strip mill, or Steckel mill. Its advantages and limitations are discussed and operating characteristics examined.

Hydraulic Control Systems for Strip Handling Equipment. J. H. Beard. (*Davy-United Engineering*, 1954, **1,** Jan., 6–12).

Reel Control Systems for Mills and Process Lines. A. J. Winchester. (*Iron Steel Eng.*, 1955, **32,** Nov., 125–134). The author describes magnetic amplifier regulating systems for tandem cold mill stand drives, and shows the advantages of these systems in reducing coil spoilage.—M. D. J. B.

Gauge Controlled Automatically on Tandem Cold Reduction Mill. (*Iron Steel Eng.*, 1955, **32,** Dec., 136–140). This article describes an X-ray gauge system for closer continuous control of cold reduced sheet and strip designed on the basis of transistor and magnetic amplifier techniques and components.

A Graphical Solution of the Cold-Rolling Problem, when Tensions are applied to the Strap. G. Lianis and H. Ford. (*J. Inst. Metals*, 1955–56, **84,** Apr., 299–305). A nomographic solution which not only gives accurate results for roll force and torque but also reduces the problem to a series of mechanical operations with pencil and straight edge is described in detail. Comparison is made, using the nomographs, with various experimental results and with more detailed calculations, and it is shown that the nomographs, cover the practical range of cold rolling conditions with a high degree of accuracy.

Setting Piercing Mills with a Displaced Piercing Axis. I. M. Ludenskiĭ and Ya. S. Finkel'shteĭn. (*Stal'*, 1955, (8), 730–733). [In Russian]. Equations are presented for calculating the setting of piercing mills in which the piercing axis is above the roll centre-lines. Some numerical coefficients are given.—S. K.

Slow Speed Sawing. (*Steel Processing*, 1955, **41,** May, 317–318). The Ryan Aeronautical Corp., U.S.A., have drastically slowed down the speed of friction sawing for many applications. Toothless blades are made from inexpensive box-strapping and clock spring material (0·050 in. × $\frac{3}{8}$ in. and 0·020 in. × $\frac{1}{4}$ in.). Tests show that these blades will cut stainless steels, mild steels, and titanium quite well at speeds as low as 4500 surface feet per minute. The burring is comparable with that formed by toothed blades, and much less than when operating at the conventional toothless speeds of 9000–15,000 s.f.p.m.—P. M. C.

Descaling by Reduction with Sodium Hydride. A. V. Smirnov, S. A. Semenkovich and F. A. Bogachev. (*Vestnik Mashinostroenniya*, 1953, **33,** (3) 37–39). After a thermodynamic discussion the descaling process with hydrogen in a sodium hydroxide melt is described, and the results and economics of the process are discussed.

MACHINERY FOR IRON AND STEEL PLANT

Handling Bulk Materials in Steel Plants. A. H. Andrews. (*Iron Steel Eng.*, 1955, **32,** Dec., 72–82). Recent ore and coal handling installations at Bethlehem Steel Co. are described. Much of the handling is done by conveyor belt systems and these are discussed in some detail.—M. D. J. B.

Blowers for Use in Iron and Steelworks. F. J. Potter and L. Duffey. (*J. Iron Steel Inst.*, 1956, **184,** Nov., 331–347). [This issue].

Magnetic Amplifier for Industrial Control Systems. R. G. Beadle. (*Iron Steel Eng.*, 1955, **32,** Aug., 132–135). The author describes the advantages of the magnetic amplifier but also discusses the limitations of the device and indicates a reasonable range of applications.—M. D. J. B.

Problems of Hoist-Control Systems of Direct-Current-Operated Steel-Mill Cranes. K. S. Kuka. (*Tisco*, 1955, **2,** Oct., 178–192). The essential characteristics of a crane-hoist control and the problems of D.C. motor stability are outlined. Transient currents and voltages and the power-type overhoist limit-switch are dealt with briefly. The essential safety features of a D.C. crane-hoist control are discussed in some detail.—L. E. W.

Transport Equipment for Cropped End of Blooms from Shears to Thomas Converter. Lanquetin. (*Centre Doc. Sidér. Circ. Inform. Techn.*, 1955, **12,** (12), 2403–2405). Equipment for transporting the cropped ends at about 1000°C from the shears to positions above each of six converters is described. Operating data obtained over a year are given.—T. E. D.

Positive-type Rotary Compressors. V. Barnett. (*J. Iron Steel Inst.*, 1956, **184,** Nov., 316–331). [This issue].

Ventilation of Steel Mill Equipment. S. L. Jameson. (*Iron Steel Eng.*, 1955, **32,** Nov., 140–151). This paper discusses fully the ventilation of electrical equipment by down-draft and up-draft systems, recirculating and non-recirculating ventilating systems, the ventilation of isolated motors, of motor rooms, air intake volumes, air-filters and the processing of fumes and dusts, electrostatic filters, fans and finally the costs of various ventilating systems.—M. D. J. B.

LUBRICATION

Roll Neck Lubrication. H. C. Inlow. (*Iron Steel Eng.*, 1955, **32,** Nov., 104–107). The author describes the adverse conditions under which the roll neck lubricant has to operate and the best means of coping with the situation. Claims are made for spray lubrication and a specification for the oil is given.—M. D. J. B.

Studies on the Wetting Effect and the Surface Tension of Solids. A Test of Lubricating Effect on the Surfaces of Shaft and Bearing. M. Sato. (*Proc. Japan Acad.*, 1955, **31,** Dec., 716–717). [In English]. Experiments with kerosene, machine oil, spindle oil, etc., show that lubricating properties can be correlated with the reduction in scratch width caused by wetting ferrous metals with the oils.—K. E. J.

The Lubricant Properties of Oil-in-Water Emulsions. J. H. Schulman and R. B. Waterhouse. (1*er Congrès Mondial de la Détergence* 1954, Section 11, 14–17). The lubricant properties are correlated with adsorption from solution on the metal (Cu and Al) surfaces.

WELDING AND FLAME-CUTTING

Steel for Welded Metallic Structures. R. Guevara Lizaur. (*Inst. Hierro Acero*, 1955, **8,** Nov., 569–612. *Special Number*). [In Spanish]. The problems and factors involved in brittle fracture phenomena in mild steels, with particular reference to welded structures, are reviewed. Methods of testing the behaviour of these steels, and specifications for fracture-resistant steels are described. An account of the author's experiences in the production of this type of steel (particularly 0·15% C, 0·20/0·50% Si, 0·9/1·2% Mn, 0·03% M. S and P, 0·025% Al) is given ; the steel-making practice and the results of mechanical and metallographic tests are detailed. (47 references).—P. S.

Welding Recommendations for Steels and other Materials. (*Welder*, 1955, **24,** Oct./Dec., 69–98). A comprehensive list is given of En steel specifications and other tables, together with recommended Murex electrodes for the manual metal arc welding of the materials concerned.—U. E.

Developments in Mechanized Welding in the Aero-Engine Industry. F. G. C. Sandiford. (*Inst. Mechanical Engs.*, 1955, Preprint, pp. 21).

Methods of Calculating Welded Joints Subjected to Static Loads. U. Guerra and U. Girardi. (*Costruzioni Met.*, 1955, **7,** May-June 16–24). [In Italian]. After a brief review of the standard methods of calculating welded joints, the authors describe the methods proposed at the 1954 Congress on metal structures and discuss the experimental evidence which can be marshalled to support these new methods.

Electrodes for Manual Electric Arc Welding. M. Patti. (*Calore*, 1955, **26,** Feb., 73–82). [In Italian]. The author reviews the developments of electric arc welding with particular reference to electrodes. The choice of electrodes, their manufacture and testing are discussed in some detail.

Selecting Electrodes and Welding Rods. H. Thielsch. (*Machine Design*, 1955, **27,** Dec., 195–199). Characteristics of the various commercially available stainless steel covered electrodes, and bare welding rods are summarized. Examples of automatic and manual welding of stainless steel parts are illustrated.—M. A. K.

The Development of an Electrode for Metal Arc Welding of Wrought 35Ni–15 Cr–1¼ Si Alloy. P. Goetcheus and R. Boring. (*Indust. Heating*, 1955, **22,** Nov., 2282–2294, 2398–2402). Metallurgical development work is described which led to the following composition C 0·78–0·85, Mn 1·5–2·0, Cr 14·5–16·5, Ni 34–37, Si 0·75–0·85% being adopted for welding Ni 35, Cr 15% steel.—A. D. H.

Evaporation of Electrodes in the D.C. Arc. G. P. Skornyakov. (*Izvest. Akad. Nauk S.S.S.R., Seriya Fiz.*, 1955, **19,** (1), 57–58). Carbon, silicon and metals were used as electrodes against copper, both as anodes and cathodes. Type 2 electrodes, comprising Fe, Co, Ni, Mn, Cr, wear equally fast as both whereas the other materials, distinguished as Type 1, evaporate more as anodes. It is suggested that Fe, Co, and Ni form negative ions.

Heat Treatment of Weld Surfaces in Stainless Steel. M. B. Shapiro. (*Vestnik Mashinostroenniya*, 1952, **32,** 63–65). The process of eliminating intergranular corrosion by high-frequency surface heating is described.

On the Nature of Weld Hot Cracking. B. I. Medovar. (*Avtomaticheskaya Svarka*, 1954, **7,** 12–28). A comprehensive review is given and a mechanism advanced related to the formation of eutectic in the weld.

Influence of Manganese on the Mechanical Properties of Welds and their Susceptibility to Hot Cracking. E. D. Lonskii. (*Autogennoe Delo.*, 1952, **23,** (10), 5–7). Experiments with welding rods of different compositions are described. An optimum value was found at 1·03% Mn, though slightly increased content, with increased carbon, caused very little falling off in regard to hot cracking.

Effect of Hydrogen, Oxygen, and Nitrogen on Hot Cracking of 18–8 Steel Welds. D. I. Medovar. (*Avtomaticheskaya Svarka*, 1953, **6,** (4), 3–9, 10–18, 18–23). The mechanism is discussed in view of the previous literature. Some experiments are described. In the second part, more trials are detailed and conclusions are drawn on the relation to microstructure. In part 3 means of prevention are considered, with the effects of Nb and V. A new welding rod is described.

The Trans-Arabian Pipe Line. J. P. M. B. Bik. (*Lastechn.*, 1955, **21,** Dec., 231–233). [In Dutch]. The article describes the installation of the 1335 km long 30 and 31 in. dia. welded steel pipe line running from the Persian Gulf to the Mediterranean Sea. The pipes were internally and externally welded longitudinally from rolled steel plate of max. 0·30% C, 0·85–1·25% Mn, 0·045% max. P, 0·04% S, and 0·12% Si in thicknesses of ¼, 5/16, ⅜ and 7/16 in. having a mean tensile strength of 45 kg/mm² and 22% elongation. Three 31 ft lengths were welded together by the Union melt process on Westinghouse welding machines installed in workshops at Ras-el-Mishaab and the resulting 93 ft length arc-welded on site by American welders ably assisted by Arab welders specially trained for the job. The whole line took about 3 years to install.—F. R. H.

Experiments on Composite Models with Applications to Cemented Joints. C. Mylenas. (*Proc. Soc. Exper. Stress Anal.*, 1955, **12,** No. 2, 129–142). The development of a new cold-setting photoelastic resin for making composite models, and its use in the construction of models of lap and butt joints is described. The photoelastic experiments on such joints indicate a variation of the stress across the thickness of the adhesive layer, and a dependence of the peak stress on the shape of the free boundary of the adhesive. There are strong indications that the stress concentration in both lap and butt joints is higher than that predicted theoretically. (20 references).—P. M. C.

MACHINING AND MACHINABILITY

Surface Machining of Rolls by the Electrospark Process. B. M. Gorbunov. (*Vestnik Mashinostroenniya*, 1953, **33,** (7), 67–70). A machine for the carrying out of the process on rolls (for flour milling) is described.

Improvement of Mechanical Properties of Metals by Means of Strain Tempering (K.R.K. Process). I. Introduction. K. Iwase, T. Sano, J. Matsuoka and M. Kyotani. **II. Application of K.R.K. Process in Steel Wire Mill.** J. Matsuoka (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** May, 230–235, 235–239). [In Japanese]. I. Strain tempering involves subjecting metal to heat, and tension, compression or torsion, for a short time ; permanent deformation follows. With wires of nickel and high-carbon steel, increases are obtained in tensile strength, elongation, torsion value and yield strength (up to 100% or more). The straightness of the wire is an advantage. II. The increase of strength by this process increases with the percentage reduction by successive drawing after patenting. The increase in strength diminishes with successive applications of the process. It should be applied successively in the first few or last few steps of reduction.

Applying Carbides to Bar Skimming. U. Wegner and H. Lindemann. (*Metalworking Production*, 1955, **99,** Dec. 30, 2209–2214). The development of fully automatic carbide skimming machines to turn high-tensile alloy steel of poor machining characteristics is described. Specially designed for carbide tools, cutting speeds of up to 400 ft per min are possible with 80 ton tensile material on these centreless bar skimming machines.—M. A. K.

Ultrasonic Impact Grinding. R. Moschella. (*Steel Processing*, 1955, **41,** June, 378–381, 399). The principles of impact grinding are briefly outlined and the choice of tools, abrasives, transducers and power supply are discussed. Several applications of the technique to the drilling of complex profiled holes and the production of stamps and dies are illustrated.—P. M. C.

CLEANING AND PICKLING

Method of Testing Degreasing Agents. G. Riedinger. (*1er Congres Mondial de la Détergence*, 1954, Section 11, 3–6). An apparatus for rapid comparison of degreasing compositions is described.

Ultrasonic Cleaning. F. Held. (*Pro-Metal*, 1955, **7**, Oct., 564–569). [In French and German]. A general review of apparatus, tests, and applications.

Some Investigations into the Acid Pickling of Mild Steel. D. Jackson. A. J. Stedman and R. V. Riley. (*Metal Finishing J.*, 1955, **1**, Oct., 435–445, 452). Laboratory tests were made to compare the pickling of standard pieces of mild steel in 10% H_2SO_4 and 20% HCl and to study the effects of temperature, inhibitors and ageing of the liquid. It is shown that 10% H_2SO_4 at 70° C is equivalent to 20% HCl at 50° C, that inhibitors have no effect on the rate of pickling and that pretreatment of the sheets in alkaline cleaning solutions had little effect. The effect of surface condition after pickling on the amount of nickel formed by galvanic displacement from a hot solution of nickel sulphate, and the effect of brightening dips were also studied.—A. D. H.

Pickling Baths of Marshalite. I. N. Nedovizii and A. L. Tarnavskii. (*Stal'*, 1955, (4), 359–361). [In Russian]. The use of marshalite for the construction of pickling baths of 1500 × 2100 mm internal dimensions is described. Reinforcement of the walls was used to pre-stress the structure and several years of service were obtained from the bath by avoidance of sudden changes of temperature; using an upper working temperature under 85°C.; and preventing direct contact of water and steam with the walls. (The solution is not made up by adding acid to water in the bath). The use of marshalite baths is said to have led to increased productivity and decreased acid consumption.—S. K.

Velocity of Passivation and Potential of an Alloy Steel KH28T3 in Sulphuric Acid Solutions. E. I. Litvinova. (*Zhur. Prikld. Khim.*, 1955, **28**, (12), 1285–1290). [In Russian]. Passivation of chromium steel (1% C, 29% Cr and 3% Ti) in sulphuric acid solutions was investigated. The stability of this alloy and the increase of potential above 0·24V was shown. This stability is preserved in the presence of chlorine and copper ions. The role of oxygen in the passivation processes of a high chromium alloy containing titanium was demonstrated. The higher the supply of oxygen to the solution, the faster the passive state is attained. On rough surfaces the passivation processes are faster than on polished ones. The relationship between the velocity of solution and the velocity of passivation was established: the higher the velocity of corrosion, the faster the passive state is attained.

Modern Installation for the Surface Treatment of Nickel Alloys and Stainless Steels. (*Draht*, German ed., 1955, **6**, Oct., 415–419). This is a detailed description of new pickling and heat treatment shops installed at the Tréfileries et Laminoirs de Précision Gilby-Fodor, at Rueil, in France, accompanied by photographs, details of the pickling solutions and particulars of the construction of the pickling baths.

Drum Polishing. J. Liger. (*Mét. Constr. Mécan.*, 1955, **87**, Oct., 813–817; Nov., 917–919). The techniques used for the cleaning and polishing of metal parts by rotation in drums are reviewed.—B. G. B.

Aspects of Electrolytic Polishing. C. A. Johnson. (*AB Metal Digest*, 1955, **1**, Sept., 3–15). An account of the mechanism of the process and of the 1715 apparatus, illustrated with micrographs.

Practical Methods for Treatment of Metal Finishing Wastes. J. C. Hesler. (*Plating*, 1955, **42**, Aug., 1019–1029). Plating waste problems are discussed generally and four examples of systems for the detoxification of liquors containing nickel, chromate and cyanide are described.—A. D. H.

Solids–Liquid Separation in the Treatment of Metal Finishing Wastes. R. F. Ledford. (*Plating*, 1955, **42**, Aug., 1030–1036). Methods of dewatering sludge by gravity or filtration are described.—A. D. H.

PROTECTIVE COATINGS

Passivation of Chrome Steels in 6·5% Nitric Acid, Copper Sulphate–Sulphuric Acid Solution, and Tap Water. C. Carius. (*Arch. Eisenhüttenwesen*, 1955, **26**, Dec., 769–776). The author describes an investigation of the corrosion behaviour of ferritic chrome steel containing 2–27% Cr in nitric acid at 22° C. He discusses equilibrium rest potentials in sulphuric acid-copper sulphate solution and tap water in 6·5% nitric acid, potential rise on passive chrome steel electrodes, boundary potentials as indices of passivation in ferritic and martensitic chrome steels, and the determination of the minimum chrome content for passivation.

A New Method of Investigation of the Mechanism of Cathodic Processes and its Uses. M. Smyalovskii and Z. Shklyarskaya-Smyalovskaya. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Khim. Nauk*, 1954, Mar.-Apr., 225–229). The extension of a coiled iron wire was observed when made the cathode to a Pt anode and cathodically polarized. Traces of Ni, Si, As, P, V, Fe, Se, and S compounds catalysed the hydrogen absorption and organic inhibitors were also tried.

Study of Electrodeposition of Metals in an Ultrasonic Field. S. M. Koshergin and N. N. Terpilovskii. (*Zhur. Fiz. Khimii*, 1953, **27**, (3), 394–398). A study of Co, Cr, Cu, Ni, Pb and Sn plating in an ultrasonic field. In general, better deposits are obtained.

Some Rules for the Change of Cathode Polarization in the Deposition of Metals under the Influence of Surface-Active Additions. Yu. Yu. Matulis and A. I. Bodnevas. (*Izvest. Akad. Nauk S.S.S.R., Otdelenie Khim. Nauk*, 1954, July-Aug., 577–586). Cu, Ag, Zn, and Ni depositions are followed with apparatus described, with addition of organic, acids and alcohols. The curves suggest adsorption effects.

Investigation of Cathodic Polarization with Simultaneous Discharge of ions of Iron and Tungsten. A. Solov'eva and A. T. Vagramyan. (*Izvest. Akad. Nauk, S.S.S.R., Otdelenie Khim. Nauk*, 1954, Mar.-Apr., 230–235). The potential for alloy deposition is lower than for either pure metal and periodic variations of potential are absent.

Rinse Water Re-Use by Ion Exchange. C. Bueltman and A. B. Mindler. (*Plating*, 1955, **42**, Aug., 1012–1018). The application and costs of anionic and cationic ion exchange resins are discussed with reference to the treatment of mixed plating shop wastes.—A. D. H.

Recovery of Plating Wastes. L. Weisberg and E. J. Quinlan. (*Plating*, 1955, **42**, Aug., 1006–1011). The methods employed to recover plating wastes at the Channel Master Co., New York, are described. Zinc cyanide is reclaimed by vacuum evaporation of the concentrated rinse water produced by four-stage countercurrent rinsing and chromate waste by an ion-exchange method.—A. D. H.

Pack Chromizing of Steel in a Mixture containing Cr_2O_3. G. N. Dubinin. (*Vestnick Mashinostroenniya*, 1954, **34**, (11), 56–81). New compositions are developed containing ammonium chloride and the effect of barium carbonate is investigated.

Hard Chromium Plating of Tool Steels. A. W. F. Comley and T. E. Such. (*Product Finishing*, 1955, **8**, Dec., 76–80, 104). Pre-treatment methods, plating bath methods and stress relieving of hard chromium plating of tool steels.

SRHS. The Self-Regulating Chrome Bath. R. Zirilli. (*Pro-Metal*, 1955, **7**, Oct., 556–563). [In French and German]. The bath described was developed by United Chromium Inc. It is so arranged as to maintain the optimum ratio of chromic acid to (sparingly soluble) catalyst at the temperature and concentration recommended. Its properties are compared with those of some commercial bath compositions and some uses are illustrated.

A New Continuous Strand-annealing and Galvanizing Installation for Mild Steel and High Carbon Steel Wires. Liekmeier. (*Draht*, German ed., 1955, **6**, Aug., 314–315). An installation by the Incandescent Heat Co. Ltd., recently put into operation at the Firth Wire Co. Ltd., Warrington, is described and illustrated.—J. G. W.

An Electrochemical Method of Removing Zinc from Galvanised Iron. N. P. Fedot'ev and G. G. Khad'mash. (*Zhur. Priklad. Khim.*, 1955, **28**, (10), 1104–1112). [In Russian]. A simple scheme for the removal of zinc from galvanised sheet scrap, consisting of treatment with a solution of sodium hydroxide, purification of the electrolyte from iron, separation of zinc by electrolysis using an insoluble anode, and resmelting of the cathode deposits. In order to obtain thick zinc deposits (1–1·5 mm) with circulating electrolyte the following electrolysis conditions are recommended. Zinc 40–50 g/l.; NaOH 200·220 g/l.; Sn 0·15–0·25 g/l., temperature 60–70°, current density 150–200 A/m².—V. G.

Can Tin–Zinc Plating Improve Your Products? F. A. Lowenheim. (*Iron Age*, 1956, **177**, Mar. 15, 92–95). The

tin–zinc plating process is described and properties and applications are given. Standard equipment can be used to plate on to most common basis metals. Coatings have excellent solderability, corrosion and abrasion resistance, ductility and appearance.—D. L. C. P.

Lead–Tin–Antimony Plating. R. T. Putnam and E. J. Roser. (*Plating*, 1955, **42**, Sept., 1133–1136). The development of a fluoborate solution for the electrodeposition of bearing alloys is described.—A. D. H.

Progress at Velindre. (*Metal Bull.*, 1956, June, 29, 11–13). A brief account of a visit to the new tinplate works of the Steel Company of Wales.

Hot Tinning Problems. G. I. Chufarov, M. G. Zhuravleva, E. P. Tatievskaya, B. D. Averbukh and V. K. Antonov. (*Zhur. Prikl. Khimii*, 1953, **25**, 652–655). A discussion of the fluxing process is presented.

Hot and Cold Ductility of Aluminium Coatings. S. G. Bogdanov. (*Vestnik Mashinostroenniya*, 1952, **32**, 48–54). Experiments on calorized specimens are described.

On the Reaction of Iron with Liquid Aluminium. E. Gebhardt and W. Köster. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 921–928). [In German]. Reaction of liquid aluminium with iron gives an adherent, pore-free, aluminium-rich zone of Al_5Fe_2 and a mixed crystal zone adjacent to the iron. The thickness varies with time according to a parabolic law. With aluminium containing zinc Al_3Fe is formed and the thickness increases linearly with time. The layer adheres very strongly and shows an increase in volume. The effect is not obtained with 16 other elements in place of zinc.

Coated Engine Valves : General Motors' Aldip Process. J. A. Edwards. (*Automobile Eng.*, 1955, **45**, Oct., 441, 442). Poppet valve heads are dipped into a molten chloride/fluoride flux at 1325° F, passed through a furnace, and then dipped for 5 seconds into molten aluminium. Compressed air then removes surplus aluminium. Valves treated in this manner give performance very superior to uncoated valves. Burning of exhaust valves is almost completely eliminated.—P. M. C.

Surface Layers of High-Melting Titanium Compounds. A. Münster and W. Ruppert. (*Zeitschrift für Elektrochemie*, 1953, **57**, 564–571). The production and properties of titanium carbide and nitride coatings on iron and other metals are described.

Weight Deposited, Yields and Losses in the Wire Spraying Process. H. Reininger. (*Metalloberfläche*, 1955, **9**, June, 81B–85B). Metal losses in the wire spraying process were investigated for zinc and aluminium spraying, and related to the area sprayed.—L. D. H.

Quality Tests for Black Oxide Coatings on Steel. J. Doss. (*Metal Finishing*, 1955, **53**, Dec., 48–50, 56). The corrosion resistance of oxide coatings formed on steel by treatment in an alkali solution containing an oxidizing agent was tested by four methods. It was found that a spot test using 5% oxalic acid solution was more reliable than the salt-fog test at present used as a standard.—A. D. H.

Investigations of the Applicability of Oxide Layers on Iron, as a Protection Against Corrosion, and as an Adhesive Undercoat for Subsequent Painting. H. Meiswinkel and V. Seul. (*Metalloberfläche*, 1955, **9**, Nov., 189A–196A). Sheet for can manufacture was oxidized by gas, aqueous solutions and fused salts, the sheet being afterwards lacquered. Using CO/CO_2 and other gas mixtures, it was found that thin oxide layers were required, but these were too porous to give adequate protection against atmospheric corrosion. Using aqueous solutions, such as chromic acid, good oxide layers were obtained which could be lacquered satisfactorily, but which were not resistant in the unlacquered condition. Using pure fused sodium sulphate good protective layers were obtained, capable of being deformed and suitable for lacquering. Certain difficulties were met with in using this process. (27 references).—L. D. H.

Oxide and Silicon Carbide Coatings for High Temperature Resistance. (*Indust. Heating*, 1955, **22**, Nov., 2352–2360). A brief description is given of a process for depositing coatings of alumina, zircon, zirconia and silicon carbide by spraying the oxide previously melted in an oxy-acetylene flame.

Enamelling of Sheet Iron and Steel. (*Syndicat National des Emailleries sur Tole. Report of a Course at Lyon, Jan.* 1951, 1954, pp. 127). **Opening Addresses.** J. Dufour, 5 ; L. Walterspiler 7–9. **General Physico-Chemical Principles.** J. Lefranc, 13–17. A review of constituents, adhesion, dilation, viscosity and surface tension. **Raw Materials.** R. Couka, 18–24. A brief review of the properties of refractory materials, fluxes, adherent oxides, and opacifiers. **Preparation of Frits and Granules.** R. Couka, 25–33. An account of the formulation, calculation, and production of frits with a note on coefficients of expansion. **Control of Frits and Tests of Enamel Quality.** G. de Surmont Jun., 34–42. An account of fusibility tests, impact testing, measurements of coefficients of expansion and optical properties, followed by a description of control of consistency, acid-resistance, resistance to alkali and to thermal shock, deformation tests, tear formation, abrasion tests, brine tests, with notes on drying and firing. **Enamel Grinding.** I. Payen, 43–45. **Iron and Steel Sheet Production.** P. Michoulier, 49–62. A general account. **Sheet Surface Preparation for Enamelling.** R. Rabot, 63–70. An account of degreasing, pickling, and drying, with an appendix on the making up of acid baths and a table of the resistance of materials to sulphuric and hydrochloric acids. **Application of Enamels to Sheets.** R. Rabot and P. Tyvaert, 71–77. A brief account of methods and tools with notes on control. **Dryers and Drying.** R. Rabot, 78–81. **Furnaces and the Firing Process.** R. Rabot, 82–86. **Faults in Enamel.** R. Rabot, 87–92. A brief review. **Titanium in Enamelling.** L. Lefranc, 93–96. Effects in steel, and use of the oxide. **Production of Thin Cast Irons for Enamelling.** E. Doat, 99–104. **Surface Preparations of Cast Iron.** P. Tyvaert, 105–113. **Enamelling of Cast Iron.** H. Crépal, 114–123. An elementary discussion. **The Role of the Foreman.** G. Douyère, 125–127.

Firing Vitreous Coatings on Steel. (*Ceramics*, 1955, **7**, Nov., 389–399). An account is given of research carried out by National Bureau of Standards, on the nature and sources of gases evolved during the firing of ceramic coatings on steel. The following are considered :—primary boil; the cloudy layer ; cooling bubbles ; pretreatment of clay.—D. L. C. P.

Quality of Steel for Enamelling. K. P. Azarov. (*Stal'*, 1955, (4), 363–367). [In Russian]. The properties and composition of steels for enamelling are considered and some special tests are described. The properties include resistance to buckling and bending, physical homogeneity (especially non-metallic inclusions and pores) and hydrogen content. The mechanism of the formation of defects in the enamel layer due to lack of physical homogeneity is dealt with. Recommended compositions of ordinary, refined and titanium steels and iron are tabulated. Apparatus for determining corrosion, buckling and tendency to flaking are described.

POWDER METALLURGY

Production of Metal Powders. M. Corsini. (*Met. Ital.*, 1955, **47**, Dec. (Special No.), 43–50). [In Italian]. A brief review is given of the principal methods of producing metal powders for sintering. These include mechanical, chemical and electrolytic methods applicable to iron, copper and copper-alloy powders as well as to tungsten and tungsten carbide powders.—M. D. J. B.

Pre-alloyed Steel Powders and their Applications. A. H. Grobe and G. A. Roberts. (*Proc. Eleventh Ann. Meeting, Metal Powder Ass.*, 1955, **1**, May, 28–40). The rotating water-jet disintegration process is described, and properties are reported of high-strength low-alloy and stainless steel powders ; properties of a type 302 stainless steel powder produced by intergranular corrosion are also described. These powders have been used to make high-strength gears, stainless filters, etc.—K. E. J.

The Compressibility of Iron Powders. J. Heuberger. (*Chalmers Tekniska Högskolas Handlinger*, 1950, No. 98, 11–20). [In German]. An expression is given for the relation between pressure and volume-density, with an account of previous equations and the results of measurements.

Evolution of Industrial Processes for the Fritting of Powders. (*Génie Civil*, 1955, **132**, Mar. 1, 90–92). A brief account is given of iron and other powders, and of the effect of copper in the consolidation of iron powder. Density, strength and elasticity are considered.

Some Observations on Sintered Steel Powder Compacts. A. A. Krishnan and B. Halder. (*J. Sci. Indust. Res.*, 1955, **14B**, Dec., 643–651). The progress of sintering of a mild steel powder in a nitrogen atmosphere was measured by determining the volume change, density, hardness and specific resistance of compacts and by metallographic study of the size and shape of the pores. A model involving inter-

face energy considerations is proposed to explain geometrically the shape and size of pores.—E. E. W.

Carbide Formation by Sintering of Complex Systems on the Basis of Fe-C. E.-M. Onitsch-Modl. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 1079–1092). [In German]. Photographic and diagrammatic studies of carbide formation are given with discussion. At temperatures of 30–50% of the absolute m.p. sintering begins. At 900°–950° carbide formation starts, at all stages the formation of iron carbide is rather less than that of the alloy carbides. From 1000°–1100° alloy carbide formation is rapid with some redissolving in the mass. Between 1100°–1200° a liquid phase appears, this closes the pores, both primary and those formed in eutectic production. The final state after the appearance of the liquid phase is 80–90% of the theoretical value.

The Interactions of Various Reactions during Sintering. H. H. Hausner. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 1051–1060). [In English]. Section B, Sintering by Cycling through the Phase Transformation Temperature, describes the sintering of electrolytic iron powder through the α–γ transformation temperature. Shrinkage, grain-size, and density are tabulated.

Self-Diffusion and Flow in Compacted Metal Powders. Ya. E. Geguzin, L. O. Markon and B. Ya. Pines. (*Doklady Akad. Nauk, S.S.S.R.*, 1952, **87,** (4), 577–580). A theoretical treatment is presented and an account of experiments on iron and copper.

Pores in Sintered Bodies in the Bragg Soap Bubble Model. J. Heuberger. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 1061–1064). [In German]. Kinematographic studies of the behaviour of vacancies in the bubble rafts are described.

Porous Metal Components : Potentialities of Sintered Metal Powders for Special Uses. (*Metal Treatment and Drop Forg.*, 1955, **22,** Jan., 3–8). A review of new developments in the field of porous metals and alloys is presented. Successful applications of porous stainless steel include the filtering of chemical solutions, de-icing of aircraft, and cooling of gas turbine blades. Brief details are given of these applications and of the manufacture by sintering of the porous metal. (6 references).—P. M. C.

PROPERTIES AND TESTS

General Study of the Systems of Units Used in France and Internationally. O. Robert. (*Rev. Gen. Méc.*, 1955, **39,** Nov., 409–416 ; Dec., 453–458 ; 1956, **40,** Jan., 37–42). A survey of these units is presented in tabular form.—B. G. B.

Collection of Thermodynamic Data for the Use of Iron and Steel Metallurgists. (*Publ. Inst. Rech. Sid.*, Series B, 1955, No. 26, Nov.). Thermodynamic data necessary for the calculation of chemical equilibria are given for 80 substances. The data are tabulated at 100° temperature intervals, and are also shown graphically to facilitate interpolation.—T. E. D.

Modern Trends in Iron and Steel Standard Specifications in Japan. H. Yoshimura. (*Tetsu to Hagane*, 1955, **41,** July, 803–812). [In Japanese]. By 1945, 520 approved and 933 provisional Japanese Engineering Standards (JES) were in existence, to meet wartime needs. These were revised in 1949. In that year a committee was established to write Japanese Industrial Standards (JIS), and the JES have been transferred ; 138 JIS applying to iron and steel exist. Recent JIS for raw materials, rolled products, compositions, steel casting and testing methods are reviewed, with tabulated notes on the 138 JIS for iron and steel.—K. E. J.

Control Systems and their Progress in Iron and Steel Plants in Japan. T. Yamaoka. (*Tetsu to Hagane*, 1955, **41,** July, 796–803). [In Japanese]. An account is given of the development of the following organizations and techniques in the Japanese industry : the Japanese Industrial Standards Research Association, statistical quality control, inspection departments, random sampling, various fuel economy measures, maintenance schemes, operational research, etc.

Progress Measurement Techniques in Iron and Steel Industry. Z. Yamauti. (*Tetsu to Hagane*, 1955, **41,** July, 787–795). [In Japanese]. An account is given of techniques introduced since 1946 concerning economy of heat utilization and measurement of high temp., e.g. the photoelectric pyrometer, colorimetric (cobalt glass) temperature determination, and immersion pyrometers. The importance of co-operative research, etc., is stressed.—K. E. J.

Method of the Quantitative Characteristic of Variability in the Evaluation of Production Quality. L. P. Vladimirov. (*Zavodskaya Laboratoriya*, 1955, **21,** (2), 184–190). [In Russian]. Statistical methods for the estimation of quality-variations, used for quality control in the production of metal parts are described.—S. K.

Contribution to the Theory of Surface Tension of Metals. S. N. Zadumkin. (*Zhur. Fizi. Khim.*, 1953, **27,** (4), 502–504). A semi-empirical formula is advanced for surface tension in terms of total surface potential barrier, work function, and number of nearest neighbours for a particle in the surface layer.

Application of Industrial Television to the Steel Industry. J. Macalla. (*Iron Steel Eng.*, 1955, **32,** Dec., 66–71). The article describes a number of uses for television cameras in the steel industry. These are mounted in hazardous or physically uncomfortable positions with a minimum of protection. Pictures taken from such vantage points can be of great use to operators. T.V. cameras are shown mounted close to continuous casting equipment, slab positioning machines, reheating furnaces, and control pulpits of tube processing lines.—M. D. J. B.

Tube Furnace for Temperatures up to 1600° C. K. Z. Gomel'skiĭ, P. N. D'yachkov, È. N. Rodigina and D. A. Startsev. (*Zavodskaya Laboratoriya*, 1955, **21,** (4), 494). [In Russian]. The construction of a double-winding electrical resistance furnace for temperatures up to about 1600° C is described. The high temperature-coefficient of the main winding secures satisfactory constancy of temperature.—S. K.

Research on Iron–Cobalt Alloys. III. Measurement of Hardness, Thermal Electromotive Force, Density and Structural Change due to the Order-Disorder Transformation. IV. On the Change of the Electric Resistance due to the Order–Disorder Transformation. T. Yokoyama. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** June, 259–263 ; 263–266). [In Japanese]. III. In plain forged Fe–Co alloys, the maxima of the thermal e.m.f. and the hardness difference produced by slow cooling and quenching occur at 26% Co, and minima at 76% Co ; these compositions indicate the formation of Fe_3Co and $FeCo_3$, respectively. IV. Resistance measurements indicate that a transformation of the FeCo superlattice may exist in the range 20–76% Co. A marked resistance change occurs in the range 40–60% Co, at 430–580° C.—K. E. J.

On the Appearance of Rolling Cracks, Grinding Cracks, and Quenching Cracks at the Centres of the Free Side of Hot-Rolled Hard Steel Bar. W. Ota. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** May, 240–243). [In Japanese]. The three types of crack, found in hard material, e.g. high-carbon chromium steel, are related to differential tensile stresses produced during rolling.—K. E. J.

Application of the Theory of Disorder in Heterogeneous Mixed Phases to the Development of Non-scaling Alloys. K. Hauffe. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg* 1952, 1954, 823–845). [In German]. Calculations are made on various assumptions for the effects of lattice vacancies on scale formation, also on the effects of foreign ions. The theories of Wagner and of Mott and Cabrera are discussed. The findings of Moore and Lea on zinc oxidation are shown to accord with the expression derived.

The Geometrical Coalescence Mechanism in Grain Boundary Migration. J. P. Nielsen. (*Rudarsko-Metalurški Zbornik*, 1954, No. 2, 105–120). Two-dimensional and three-dimensional grain boundary structures are discussed and mathematical expressions derived. Polycrystalline structures are then described and secondary recrystallisation, grain growth and recovery considered qualitatively.

Theory of the Formation of Lattice Defects during Plastic Strain. H. G. Van Bueren. (*Acta Met.*, 1955, **3,** Nov., 519–524). A theoretical discussion of the detailed processes occurring in cold worked metals is made and applied to the case of a face-centered cubic lattice deformed at low temperatures.—A. D. H.

Improvement of the R-5 Testing Machine. Kh. N. Dement'ev. (*Zavodskaya Laboratoriya*, 1955, **21,** (2), 239–240). [In Russian]. A brief account is given of an improved design of dash pot for a Soviet testing machine.—S. K.

On the Solution of the Fundamental Problem of Buckling and its Meaning as a Guide to the Ordinary Methods of Testing. M. Broszko. (*Bull. Acad. Polonaise Sci.*, 1954, **2**, No. 3, 115–118). [In German]. Equations are derived for critical load in terms of ratio of length to diameter and other parameters.

On the Deformation of Steel Tensile Rods at High Rates. E.-J. Giessmann. (*Arbeitstagung Festkörperphysik II*, 1955, Leipzig, 77–81). An account of anomalies appearing when tensile tests are carried out rapidly. Five types are distinguished according to the plot of load against extension. Deformation in a " static " test is analysed and the results are discussed.

Metallurgical Aspects of Strength at Elevated Temperatures. G. V. Smith. (*Proc. Soc. Exper. Stress Anal.*, 1954, **12**, No. 1, 155–162). It is shown that creep characteristics and other strength properties at elevated temperatures of carbon, alloy and stainless steels may be affected by metallurgical variables such as chemical composition, refining and deoxidation practices, and heat-treatment. Examples showing the magnitude of the possible effects are given. The action of time and temperature in service may also alter structure and hence properties. (16 references).—P. M. C.

Calculation of Tensile Strength in the Drawing of Steel Wire. O. Kowalski. (*Draht*, German ed., 1955, **6**, Aug., 312–313). Nomograms relating inlet and finish size of wire, total reduction, and final tensile strength, are presented by reference to a table of tensile strength for 9 grades of wire.

The Application of Factorial Analysis to the Comparison of the Tensile Strengths of Different Types of Cast Iron Test Pieces. J. Gélain and A. Barat. (*Fonderie*, 1955, Oct., 4729–4734). Tensile test results obtained on two cast irons using bars cast at two different temperatures and with three different feeding systems are analysed statistically to determine the significant variables. The design of two different tensile specimens is also discussed and the results obtained with them are analysed by the Student test to show that one design was superior in regard to the number of specimen failing outside the gauge length.—B. C. W.

Determination of the Yield-points of Metals by Measurement of the Propagation of Sound. Its Application to Cast Iron. H. J. Seeman and H. Schmauch. (*Rev. Mét.*, 1955, **52**, No. 8, 621–628). The static and dynamic methods for physically testing metals are briefly reviewed and the application and measurement of sound waves discussed. Experiments carried out with graphitic cast iron are described and the results compared with those obtained by the more classical static methods.—G. E. D.

Residual Stresses. (*Metal Progress*, 1955, **68**, Aug. 15, 89–96). Factors causing the development of residual stresses in metals are considered in detail. Thermal and mechanical processes are reviewed. The effect on the properties of the metal of residual stresses are discussed and thermal and mechanical methods of stress relief are considered. The mathematical principles of a number of methods of measuring residual stress are explained.—B. G. B.

Measurement of Deformation in the Determination of Residual Stresses. K. S. Kolev. (*Zavodskaya Laboratoriya* 1955, **21**, (6), 750). [In Russian]. A brief description is given of a procedure for measuring the stresses in a mechanically worked metal surface.—S. K.

Investigation of Axial Residual Stresses with the Aid of a Type IZP-17 Profilograph. D. D. Papshev. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 601–603). [In Russian]. A simple method is described for measuring axial residual stresses in which the changes in the dimensions of the test-piece accompanying the removal of the stressed layers are followed with the aid of a profilograph. Tests were carried out on machined steel sleeves. The sleeve was stood vertically in a tank containing an electrolyte, the profilograph needle resting on the top rim of the sleeve, and the surface layers of the sleeve were gradually removed by electrolytic polishing. Residual stresses for sleeves produced by ordinary and high-speed turning were measured.—S. K.

Methods of Determining Residual Stresses in Butt Joints of Tubes of Steels with Different Coefficients of Thermal Expansion. A. S. Gel'man and V. S. Popov (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 722–724). [In Russian]. Using as an example a butt joint between tubes of a pearlitic and an austenitic steel, a method of calculating residual stresses in this type of welded joint is developed. Results for alloy-steel tubes are presented. The method is restricted to thin-walled tubes.—S. K.

The Present Position of Strain Measurement by Means of X-Rays. V. Hauk. (*Arch. Eisenhüttenwesen*, 1955, **26**, May, 275–278). The various influences to be considered in strain measurement by X-rays are discussed and the fundamental equations given. Five material or deformation states are distinguished: homogeneous isotropic material in the elastic region, and homogeneous or heterogeneous anisotropic material in the elastic and plastic regions. Internal stresses after permanent set are considered. The development of internal stress after etching is discussed.—A. C.

Determination of Internal Stresses in Water-quenched Steel Cylinders. H. Bühler and H. Hendus. (*Arch. Eisenhüttenwesen*, 1955, **26**, June, 355–358). The authors describe determinations of the thermal tensions in steel cylinders quenched below A_1 after boring or turning, X-ray reflection technique, observations of the deformation of the outer surfaces with strain gauges, and the effect of end-area on the internal stresses at the outer surfaces. They compare various methods of dtermining the mean values of X-ray results.—A. C.

The Properties of Steel in Relation to its Behaviour in Welded Structures. E. Houdremont and H. J. Wiester. (*Schweissen u. Schneiden*, 1954, **6**, Special Issue, 16–23). The iron lattice is briefly discussed. A review is given of data on the effect of stress distribution, stress velocity and temperature on the structure of iron and steel and special attention is drawn to the serious effect of stresses on the tendency to brittle fracture. The choice of the right type of steel for welding is discussed from the economic aspect.—U. E.

Experiment in the Electro-Tensometric Testing of Steam Boilers. F. F. Benua and P. N. Shilyaev. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 603–606). [In Russian]. The use of resistance strain-gauges for testing boiler-shells is considered with special reference to thermal compensation and gauge attachment.—S. K.

Examination of Boiler Tubes. A. H. da Silveira Feijo. (*Bol. INT.*, 1952, **3**, May, 1–20; Sept., 14–32). [In Portuguese]. The tubes examined had failed in a naval boiler explosion. The steel analysed 0·11–0·17% C, 0·51–0·53% Mn, 0·01% P, 0·008–0·011% S, 0·06–0·09% Ni. A coarse martensitic structure was formed not only in the vicinity of the failure but also in the diametrically opposed zones which had not undergone any plastic deformation. This indicated intensive tempering and the hot steam and water which escaped during the explosion would not prevent the formation of martensite since a temperature of 425° C would suffice for the transformation. The failures were evidently due primarily to superheating of the tubes caused by local or general deficiency of water, the presence of extraneous bodies in the water tubes, local scaling, abrupt fluctuations in the steam pressure and local contact with the flame.—R. S.

Examination of a Steel Cable. A. H. da Silveira Feijo. (*Bol. INT.*, 1953, **4**, Jan., 12–29). [In Portuguese]. An examination was carried out to reveal the causes of failure of a carbon steel cable which had caused an accident on the Pão do Açucar (Sugar Loaf Mountain in Rio de Janeiro). The failure was apparently due to fatigue. Bend tests produced failure of the wire rope after only nine cycles. French aeronautical standards (to which the wire had been supplied) specified sixteen bending cycles. Requisite properties for this type of cable are discussed and full details of the tests by the Brazilian National Institute of Technology (INT) are given.—R. S.

Examination of a Steel Crankshaft. A. H. da Silveira Feijo. (*Bol. INT.*, 1953, **4**, May, 9–17). [In Portuguese]. A Diesel marine engine crankshaft was examined for an apparent fatigue failure. The part had been repaired by welding and apparently spoilt by local hardening effects. The original steel was to A.S.T.M. specification A-21-36 (0·48% C, 0·22% Si, 0·83% Mn, 0·028% P and 0·011% S) and contained much more pearlite than the welded deposit. There was a distinct difference between the structure of the centre portion and of the zone adjacent to the weld. Internal stresses had been set up, causing an expansion of the fatigue micro-cracks and finally leading to fatigue failure.—R. S.

Fatigue Machine for Testing Steel-Cable Wires with Complex Loading. A. M. Pen'kov and A. M. Vorobeĭkov. (*Zavodskaya Laboratoriya*, 1955, **21**, (7), 860–862). [In

Russian]. In the new design of machine for fatigue-testing steel wire described, the service conditions encountered in steel cables are approximated by subjecting the test-piece to bending torsional and tensile loads. The wire is bent into arcs of fixed radii having a fixed relation to the wire diameter. The machine can deal simultaneously with ten wires 72–200 mm in length and 0·3–3 mm thick.—S. K.

New Method of Evaluating the Fatigue-Strength of Surface Layers and Coatings. N. M. Rudnitskiĭ. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 590–594). [In Russian]. The effects of electrolytic and other deposits on the fatigue behaviour of the parts they cover are discussed and the evaluation of such effects on the basis of the deformation-properties of the deposited material is considered. The deposition of alloys rather than pure metals is recommended.

Tests on a New Machine for Corrosion-Fatigue Testing with Wire Test-Pieces. V. I. Kazarin, V. A. Titov and N. D. Tomashov. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 618–620). [In Russian]. In the new corrosion-fatigue testing procedure described, a wire test piece is rotated about its longitudinal axis when bent into an arc and immersed in the test-liquid. Results obtained with iron wire (0·023% C, 0·032% Mn, 0·18% Cu, 0·018% S, 0·010% P and traces of silicon) in various liquids confirmed the conformity between the dependence of corrosion fatigue and the value of the rate of ordinary unstressed corrosion on temperature, pH value, chlorine-ion concentration (when oxidizing agents are present) and the electrode-potential value of the wire test-piece.—S. K.

Automatic Recorder of the Duration of Vibration Processes. A. V. Antonovich. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 728–731). [In Russian]. A description is given of an automatic device for recording the end of a vibrated process, such as in determinations of fatigue-limits with flat test-pieces under reversed-sign bending loads. The device can deal simultaneously with several test-pieces. The test-piece and a movable plate form a condenser with air as dielectric, which emits a signal during the vibration. Provision is made for autographic recording of the process. The method is applicable to other processes where the number of cycles or operations in time must be measured.—S. K.

Loosening and Fatigue Strength of Bolted Joints. M. Boomsma. (*Engineer*, 1955, **200**, Aug. 26, 284–286). This article surveys and comments upon existing knowledge about the loosening of bolted joints under variable tension loads; the effect of bolt length and bolt diameter on loosening; the advantage of using many small bolts instead of a few large ones and the fatigue strength of bolted joints with comparatively rigid abutments. (12 references).—M. D. J. B.

The Value of Hardness Testing after Frontal Quenching. V. Wyss. (*Härterei-Tech. Mitt.*, 1953, **6**, (2), 9–40). The method is described and results for hardness in varying sections are quoted. A relationship between hardenability, hardness, structure, application and properties of steels is arrived at. (13 references).—R. P.

A New Development in Micro-Hardness Testing. P. Grodzinski. (*Härterei-Tech. Mitt.*, 1950, **6**, (1), 31–53). A critical survey of existing micro-hardness testing methods is made, together with their applications. A new definition is suggested. (15 references).—R. P.

The Influence of Carbide Formation on the Performance of High-Speed Twist Drills. A. Gühring. (*Härterei-Tech. Mitt.*, 1953, **8**, (2), 9–19). The author describes tests carried out to show how the size and form of carbides depend on the grain size, hardness and elasticity of high-speed toolsteels. Twist drills with diameters less than 20 mm. are tested in particular. Small grain size is advocated in order to facilitate hardening.

Deep-drawing Properties of Steel Strip. I. Effect of Vanadium on the Strain Ageing of Rimmed Steels. Y. Shimokawa and T. Fujii. (*Sumitomo Metals*, 1955, **7**, July, 137–143). [In Japanese]. Additions of vanadium up to 0·8% to rimming steel showed that: tensile strength and elongation are not affected, but yield strength is reduced and deep-drawing properties are improved; the ageing speed and time of isothermal recrystallization are reduced with increase of V content; and the grain size of ferrite and austenite are slightly reduced.—K. E. J.

Investigation of the Quench-Ageing of Soft Unalloyed Steels, Using Radioactive Isotopes. H.-K. Görlich, H. Goosens and H. Schenck. (*Arch. Eisenhüttenwesen*, 1955, **26**, July, 389–391). A method is described of examining the process of quench-ageing of soft, unalloyed steels, using radioactive isotopes—mainly carbon C_6^{14}. The suitability of the method was demonstrated using a 0·01% carbon steel quenched in water from 680° and kept at room temperature for 25 weeks. The steel was activated by carburization in barium carbonate ($BaC_6^{14}O_3$ followed by re-melting.—A. C.

Examination, by Hardness Testing at Temperatures up to 300°, of the Ageing of Soft Unalloyed Steels. E. Houdremont, W. Wepner, and H. J. Wiester. (*Arch. Eisenhüttenwesen*, 1955, **26**, May, 279–285). A considerable number of steels were examined to determine whether and how far the increase of hardness between temperatures of about 200 and 250° permitted differentiation with respect to their ageing characteristics. Reference is made to the effect of annealing at 250°, the influence of nitrogen and carbon content, and the effect of aluminium.—A. C.

Interpretation of the Brittleness of Iron–Chromium Alloys at 475° C. E. Josso. (*Compt. Rend.*, 1955, **240**, Feb. 14, 776–778). A new interpretation is proposed for the brittleness, which occurs in iron-chromium alloys at 475° C, based on the existence of an order-disorder transformation, which favours the eventual precipitation and bringing into solution of a second phase rich in chrome.—G. E. D.

Experiments on Brittle Fracture of Steel Plates. D. K. Felbeck and E. Orowan (*Welding, J.*, 1955, **34**, Nov., 570s–575s). Tensile tests at room temperature on ship plate specimens provided with brittle edge cracks of various lengths are described. The fracture stress was found to be inversely proportional to the square root of the initial crack length. The initial brittle crack did not propagate directly as such but first changed into a very short fibrous crack, with considerable plastic deformation around its tip, then changing into a brittle crack. It is concluded that the decisive factor in the brittle fracture of low-carbon steels is the high velocity dependence of the yield stress.—U. E.

The Relation Between Brittle Behaviour and the Strength and Structure of Materials. F. J. Hiorns. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19**, Feb., 49–60). Theories and experiments on the brittle fracture of simple materials are reviewed. (104 references).—D. L. C. P.

Strength and Plasticity of Metals at Low and Very Low Temperatures. G. V. Uzhik. (*Izvest. Akad. Nauk. SSSR, Otdelenie Tekn. Nauk*, 1955, (1), 57–66). [In Russian]. An investigation of changes in strength and plasticity of steels and non-ferrous metals with decreasing temperature down to −253° C is given. The apparatus used is described in some detail.—V. G.

Internal Friction in Steel and Temper Brittleness. (*Izvest. Akad. Nauk. SSSR, Otdelenie Tekn. Nauk*, 1955, (1), 157–159). [In Russian]. The relationship between temper brittleness and internal friction of steel was investigated. It was found that internal friction of steel, evaluated by the relative damping of free torsional vibrations, reacts to a large extent on processes causing temper brittleness. The latter considerably increases the internal friction of metal due to impoverishment of a solid solution (ferrite) in carbon which is consistent with present views on the nature of internal friction. The reversibility of the processes causing temper brittleness by a high temperature treatment leads to the reversibility of the internal friction. The tendency of steel to temper brittleness can be detected by measurements of its internal friction.—V. G.

Room Temperature Grade Propagation and Size Effect on Mild Steel. J. D. Gubahn. (*Welding J.*, 1955, **34**, Oct., 518s–528s). The nature and behaviour of fracture in mild steel during room temperature notch-bend tests is investigated. Load-deflection curves for V-notch Charpy specimens of different sizes are presented.—U. E.

A 600 Ton Test Rig for Brittle Fracture Research. A. A. Wells. (*Brit. Welding J.*, 1956, **3**, Jan., 25–30). A 600-ton test rig is described which employs hydraulic capsules. The test rig was developed by the British Welding Research Association.—U. E.

Evaluation of a Method for Determining the Tendency of Mild Steel to Brittle Fracture. (Report SR 532/1A *Centrum voor Lastechniek N.V.L.-T.N.O.*, April, 1955, pp. 99). Introduction and review of experiments, 9–19. Notched-bar impact tests, 20–29. Static tests on unwelded specimens, 30–50, comprising: 1. The Doete slow four-point bend test. 2. The slow bend test on sharp-notched specimens; with evaluation of results and discussion of criteria of ductility

and fracture appearance. 3. Transition temperatures, statistical comparisons, and theoretical considerations.

Static tests on welded specimens, 51–59, comprising Kommerell tests and effects of welding on transition temperature. The conclusions, 60–62, are presented as requirements to be met by a suitable test and criteria for measuring the tendency to brittle fracture, followed by considerations regarding a choice from existing methods. The view adopted by the Research Committee is:

A. Among test methods investigated, the slow bend test on sharp-notched specimens developed by Van der Veen is that most suitable.

B. If the amount of material available, or the thickness of the material, or some other circumstance, necessitates the use of the impact test, the Charpy type specimens with V-notch (Izod Notch) is preferred. Detailed test results are given in Appendices 63–99.

Some Observations on Temper Brittleness. L. Colombier. (*Rev. Mét.*, 1955, **52,** No. 8, 643–657). The occurrence of temper brittleness was investigated in alloy steels by varying the amount of a single constituent and studying the resulting change in the transition point of the tensile strength/temperature diagram. In this way, the effects of silicon, nickel, chrome and silicon-nickel and chrome-nickel combinations, all of which favour temper brittleness, were investigated.—G. E. D.

Measuring Gear Wear By Geiger Counter. F. L. Schwartz and R. H. Eaton. (*S.A.E. J.*, 1955, **63,** Apr., 21–24). A method of determining the rate of gear wear is described in which the gear is made radioactive, following which the worn off particles of metal are circulated in oil past a geiger counter. The calibration of the equipment and some typical test results are discussed.—P. M. C.

War on Wear. V. Caldwell. (*Steel*, 1955, **137,** Nov. 28, 98–101). Courses and means of minimizing the wear of metals are considered. Recent developments in surface treatments are mentioned.—D. L. C. P.

Quantitative Determination of Wear of Machine Parts Using Radioactive Indicators. Yu. S. Zaslavskii and G. I. Shor. (*Izvest. Akad. Nauk. SSSR, Otdelenie Tekn. Nauk*, 1955, (4), 43–52). [In Russian]. Quantitative determinations of wear of machine parts by measuring radioactivity of oil samples collected at certain time intervals or by inclusion of a counter in the oil circuit are outlined. A method of rapid evaluation of the influence of the quality of oils and fuels on engine wear based on a continuous recording of radioactivity of the oil used, developed by the authors is described.—V. G.

The Division of Heat Between Rubbing Bodies When Their Relative Movement is not Periodic. P. Vernotte. (*Compt. Rend.*, 1954, **239,** Dec. 20, 1773–1775). By taking account of the heat capacities and the conductivities of two dissimilar bodies, the one sliding over the other, it is possible to determine the distribution of frictional heat between them.—G. E. D.

Paramagnetic Properties of Austenitic Alloys Containing Various Amounts of Chromium. V. I. Prosvirin and S. Y. Sigolaev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (7), 96–100). [In Russian]. Magnetic susceptibility of 5 austenitic alloys containing from 5 to 28% of chromium and quenched from 3 different temperatures was investigated in the temperature region 20–800°. It was found that magnetic susceptibility of all alloys decreases with increasing temperature, the values obtained increase with decreasing chromium content. Increasing of annealing time causes periodic changes in magnetic susceptibility which are explained by the formation and decomposition of carbide phases.—V. G.

On the Magnetic Ageing of Pure Iron (II). M. Asanuma and S. Ogawa. (*J. Phys. Soc. Japan*, 1955, **10,** Nov., 1025–1026). It was ascertained by means of experiments that the decrease of initial magnetic susceptibility with time is consistent with the hypothesis of the precipitation of $Fe_{16}N_2$ being the dominant cause.—J. G. W.

Hall Effect in Permalloys. S. Foner. (*Phys. Rev.*, 1955, **99,** Aug. 15, 1079–1081). Comparison is made of the Hall effect for 25% and for 55% iron in nickel with that for some Co–Ni and Fe–Ni alloys.—E. E. W.

Gyromagnetic Ratio of Iron at Low Magnetic Intensities. G. G. Scott. (*Phys. Rev.*, 1955, **99,** Aug. 15, 1241–1244). The practical values of the ratio for pure iron—obtained by a direct magneto-mechanical method—are compared with theoretical values.—E. E. W.

Stabilization of Permanent Magnets. H. Krainer. (*Arch. Eisenhüttenwesen*, 1955, **26,** Aug., 491–496). Permanent magnets were stabilized by cyclic variation of the strength of a negative external field. Diagrams of induction *v.* field strength are given and discussed in detail.—A. C.

Electronic Energy Bands in Iron. J. Callaway. (*Phys. Rev.*, 1955, **99,** July 15, 500–509). A method of orthogonalized plane waves is described for calculating the energy band structure of valency electrons in iron. An application is made to the theory of ferromagnetism.—E. E. W.

Initial Permeability of Some Ferrous Materials Under Mechanical Strain. W. Jellinghaus and K. Janssen. (*Arch. Eisenhüttenwesen*, 1955, **26,** July, 405–419). The initial permeability under tensile strain was measured for specimens of technically pure iron, unalloyed steel containing 0·45% carbon, steel containing 3·4% silicon, and an iron-nickel alloy containing 75·6% nickel. The results differ from those of Langevin, Paul and Reimbert, and this is attributed to the differences of experimental procedure. The least value of alternating field necessary for idealization was calculated theoretically, and the result confirmed by experiment. Neel field theory was used to evaluate the effect of non-magnetic inclusions on the initial permeability under mechanical strain. Theoretical and experimental results are compared.—A. C.

Experimental Result of Thickness Measurement by a Cathode Ray Tube Type Supersonic Thickness Gauge "Sonizon." E. Miyoshi and K. Kawano. (*Sumitomo Metals*, 1955, **7,** July, 155–166). [In Japanese]. Calibration results are presented for plate and wall thickness measurements, and defect location, with the "Sonizon" ultrasonic gauge.—K. E. J.

Methods of Bond Testing. W. J. McGonnagle, J. H. Monaweck, and W. G. Marburger. (*Non-Destructive Test*, 1955, **13,** Mar.–Apr., 17–22). An investigation is described in which the thermographic, electrode potential, and ultrasonic methods of testing were applied to the detection of unbonded areas in fusion welded metal laminates. The data show that the ultrasonic method was the most sensitive, the electrode potential method moderately sensitive, and the thermographic method the least sensitive. 3 references.

The Sound of Quality Control. J. E. Rutledge. (*Non-Destructive Test.*, 1955, **13,** Mar.–Apr., 13–16). The meaning of and importance of the terms "quality control," and "inspection" for industry in general are described. The author then discusses the experience of the McDonnell Aircraft Corporation in applying ultrasonic inspection, and its significance to the aircraft industry.—P. M. C.

Determination of Elastic Constants of Solids by Ultrasonic Diffraction Methods. G. S. Verma. (*Nature*, 1955, **176,** July 2, 27–28). Elastic constants for a number of crystalline materials, including steel, have been measured.—B. G. B.

Standardization In Ultrasonic Testing. C. W. Cline and J. B. Morgan. (*Non-Destructive Test.*, 1955, **13,** July–Aug., 23–27). The importance of standardization of the procedures employed in ultrasonic testing is emphasized. The authors describe the design and use of reference blocks containing artificial defects, and the uses of electronic checking equipment and monitors. The data are based on experience with aluminium alloys.—P. M. C.

The Thermal Conductivity and Electrical Resistivity of an 0·4–0·5% Manganese Steel. R. W. Powell and R. P. Tye. (*J. Iron Steel Inst.*, 1956, **184,** Nov., 286–288). [This issue].

How Deep is that Crack? H. N. Staats. (*Non-Destructive Test.*, 1955, **13,** July–Aug., 21–22). A brief description is given of the principle and uses of an eddy current instrument designed to measure the depth of cracks in billets and similar stock. The instrument is marketed by Magnaflux Corp., under the trade name Sedac, and measures depth of defects in the range 0·012 to 0·120 in.—P. M. C.

Progress in Ultrasonic Examination. 1. Automatic Immersed Scanning. C. W. J. Vernon. (*Welding Metal Fab.*, 1956, **27,** Mar., 93–97). The principle of the pulse echo method of ultrasonic flaw detection by contact scanning is described.—U. E.

The Feasibility of Fluorography Above 150 kV. D. Polansky and D. T. O'Connor. (*Non-Destructive Test.*, 1954, **12,** Nov.–Dec., 27–34, 46). Evidence is offered to support the contention that fluorescent screens are capable of a highly

discriminating brightness response at least up to 2 Mev X-ray excitation, even though this energy is far above their peak response energy. The fact that lead filters are effective in removing scattered radiation to which such materials are more responsive makes it possible to achieve penetrameter sensitivities of the order of 2% with fluorography at 2 Mev. If this quality level is adequate, fluorography at higher energies combined with rapid automatic processing may offer an economical approach to some inspection problems. The whole process and technique is discussed in some detail. (29 references).—P. M. C.

The Portable 1-Million-Volt X-Ray Generator. E. A. Burrill. (*Non-Destructive Test.*, 1954, **12,** Nov.–Dec., 23–24). The physical, radiation, and radiographic characteristics of the 1 million-volt Van de Graaf X-ray generator are briefly outlined. Radiography in the steel thickness range of ½ to 5 inches can be performed with good sensitivity and definition, and with short exposure times. The self-contained design permits great flexibility in movement and transportability, and the cost of the unit is similar to that of conventional X-ray equipment. (3 references).—P. M. C.

Cast Metals in Naval Construction and More Particularly in the Construction of Propelling Machinery. The Conditions of their Control and Acceptance. J. Tigeot. (*Fonderie*, 1955, June, 4543–4550). The quality control and acceptance tests applied to castings for marine engines are briefly reviewed and a description is given of some of the radiographic methods used for examination of the castings.—B. C. W.

Method and Apparatus for Measuring the Thickness of Rolled Steel Products with the Aid of Radioactive Radiation. A. M. Bogachev, B. I. Verkhovskiĭ and A. N. Makarov. (*Zavodskaya Laboratoriya*, 1955, **21,** (7), 813–820 and 850–852). [In Russian). Apparatus developed for thickness determinations with the aid of radioactive radiation is described which combines the advantages of the absolute with the high accuracy of the comparative method. The principle of the method is the comparison of two beams, one passing through the material to be measured, and a compensating beam which falls directly on the detector; the electrical signals produced by the beams are automatically equalized by a shutter in the compensating beam, the position of the shutter then being a measure of the thickness. Three forms of the apparatus are described. In the second paper a similar method for measuring the thickness of a tinplate layer is described.—S. K.

Theory of the Method of Measuring Thickness with the Aid of Radioactive Radiation. A. M. Bogachev, B. I. Verkhovskiĭ and A. H. Makarov. (*Zavodskaya Laboratoriya*, 1955, **21,** (7), 808–812). [In Russian]. The accuracy of the absorption method of thickness determination with the aid of radioactive radiation and the selection of the radioactive isotopes and of the activity of the source are considered.—S. K.

Non-destructive Testing of Welds and Crack Detection. (*Schweissen u. Schneiden*, 1955, **7,** Dec., 507–514). A summary of a lecture delivered at Essen/Ruhr on January 14, 1955, by H. Stäger. The use of gamma rays (radio-active isotopes) in testing of welds and the ultrasonic test method are discussed. A number of practical applications are illustrated.—U. E.

An X-ray Examination of Preferred Orientation and the Transformation $\gamma \rightarrow \alpha$ in a Stainless-steel Wire. K. W.. Andrews. (*J. Iron Steel Inst.*, 1956, **184**, Nov., 274–286) [This issue].

X-Ray Structural Method of Investigation. (*Zavodskaya Laboratoriya*, 1955, **21,** (5), 515–517). [In Russian]. Uses of X-ray analysis for the investigation of steels and materials involved in the production of iron and steel are reviewed.—

The Development of Non-destructive Testing and the Problem of its Application. M. Pfender and O. Vaupel. (*Schweissen u. Schneiden*, 1954, **6,** Special Issue, 24–33). Different non-destructive test methods as applied to welded structures are discussed, as for example, surface testing (etching), the use of *X*-rays and gamma radiation, electric and magnetic methods and damping capacity tests including the ultrasonic method.—U. E.

Non-destructive testing of Material and its Limitation in Practice. P. Gayer. (*Schweissen u. Schneiden*, 1954, **6,** Special Issue, 33–37). The limits of application of non-destructive testing of welds are discussed with illustrations.—U. E.

X-Ray and Gamma-Ray Safety Precautions. (*Brit. Welding J.*, 1956, **3,** Apr., 143–148. British Welding Research Association Report FE.18RP/10E). The paper aims at setting out the essential precautions for safeguarding personnel from the injurious effects of radiation.—U. E.

Some Curves from a Portable Differential Thermal Analysis Unit. C. J. Parker, J. C. Hathaway, and P. D. Blackman. (*U.S. Geol. Survey Bull.* 1956, 1021–9). Curves for some refractory materials are included.

Raising the Sensitivity of a Technical Dilatometer with Mechanical Recording. E. N. Kislyakova. (*Zavodskaya Laboratoriya*, 1955, **21,** (2), 240–241). [In Russian]. Minor modifications of design and longer test-pieces led to improved sensitivity of a dilatometer used in the works investigation of the tempering of high-carbon and alloy steels.—S. K.

The Relationship Between Composition, Temperature and Heat Resistance. II. Ternary Alloys Nickel–Chromium–Titanium. I. I. Kornilov and V. V. Kosmodem'yanskii. (*Izvest. Akad. Nauk. SSSR, Otdelenie Tekn. Nauk*, 1955, (2), 90–97). [In Russian]. The above relationship was investigated in the temperature region 500–1200° C. Altogether 20 alloys containing 20% of chromium and between 0–10% of titanium were studied. It was found that the heat resistance of the above alloys is related to polythermal solubility of titanium.—V. G.

Properties and Production of a Heat-Resistant Casting Alloy. R. Radtke. (*Giessereitechn.*, 1955, **1,** Nov., 211–215). The theory and practice of producing castings with reduced chromium content are discussed. The scaling process, the effect of alloying elements, the substitution of silicon for chromium, and analyses of melts, are described.—L. J. L.

Attachment for a Type MI Machine for Friction Tests at High Temperature. A. A. Yavnel'. (*Zavodskaya Laboratoriya*, 1955, **21,** (6), 751–752). [In Russian]. A furnace for attaching to a friction-testing machine to enable tests to be carried out at temperatures up to 700° C is described.—S. K.

Contributions to the Mechanism of the Diffusion of Copper in Iron. F. Širca. (*Rudarsko-Metalurški Zbornik*, 1955, No. 1, 25–33). An account is given of a study of the diffusion of electrolytic copper into Armco iron at temperatures from 750° to 1150°C. The intergranular diffusion is more rapid than the volume diffusion except in α-iron.

Behaviour of Steels exposed to Hydrogen under High Pressure. O. van Rossum. (*Chem.-Ingenieur Technik*, 1953, **25,** 481–484). A two-stage mechanism is advanced for the failure of steels at temperatures up to 1040° F and pressures up to 700 atmos.

The Mechanism of Diffusion of Cathodic Hydrogen into Iron. M. Smiatowski and Z. Szklarska-Smiatowska. (*Bull. Acad. Polonaise Sci.*, 1953, **1**, No. 7, 327–331). The expansion of a fine wire was studied when made the cathode of an electrolytic cell. The causes of diffusion appeared to be a high atomic hydrogen pressure on the surface, and electrocapillary effects.

Nitrogen as an Alloying Element in Steels. XIII. On the Effect of Nitrogen on the Decrease of Impact Resistance at 0° C. XIV. On the Effect of Nitrogen and Phosphorus Contents on the Decrease of Impact Resistance at 0° C. Y. Imai and T. Ishizahi. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** May, 209–212 ; 212–216). [In Japanese]. XIII. Charpy impact tests were made on steels containing C 0·15%, Mn 0·30%, Si 0·15% and N 0·003–0·030%. As nitrogen contents increased, the impact resistance at 0° C decreased, and the decrease in impact resistance after cold work was pronounced. There is a correlation between the latter and strain-ageing due to nitrogen. The addition of aluminium or titanium to fix nitrogen arrested these trends. XIV. Similar tests were made on steels of similar composition to the above, containing N 0·003–0·030%, or N 0·004% and P 0·003–0·300%. Phosphorus reduced the impact resistance, but the over-riding effect of nitrogen was recognized.—K. E. J.

Nitrogen as the Alloying Element in Steel. X. The Effect of Nitrogen on the Elongation at the Yield-Point and the Serrated Deformation in Steel. Y. Imai and T. Ishizaki. **XI. The Effect of Nitrogen on the Corrosion Resistance of Steels.** Y. Imai, Y. Ishizaki and K. Shishido. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** June, 275–279 ; 279–282). [In Japanese]. X. Elongation at the yield point is attributed to nitride or carbide pptd. from α-iron at 0–250° C. Serrated deformation is due to the same compounds pptd. through working stress.

XI. Corrosion resistance is decreased by increase of

nitrogen content in annealed or cold worked specimens. The effect can be neutralized by suitable additions to remove nitrogen in the molten steel, or by annealing in hydrogen.

The Influence of Niobium and Titanium on the Properties of Stainless Steel. A. M. Samarin and A. A. Yaskevich. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1955, (10), 107–116). [In Russian]. Mechanical properties, resistance to corrosion and weldability of four stainless steels (2 alloyed with titanium and 2 alloyed with niobium) were investigated. Resistance to intercrystalline corrosion of niobium alloyed stainless steel is higher than that alloyed with titanium. In addition, niobium improves the weldability of steel.—V. G.

Answers to 10 Questions Help You Pick the Right Steel. J. J. Hauptly. (*Mat. Methods*, 1955, **42,** Sept., 86–93). Assuming a prior knowledge of the required strength, the heat-treating procedure and a familiarity with the manner of fabrication of a particular component, a series of ten questions are proposed which in conjunction with a table purport to select (*a*) the group of steels most suitable and (*b*) the particular steel from within the group.—P. M. C.

Bolting Materials for High-Temperature Steam Plant Service. M. G. Gemmill and J. D. Murray. (*Engineering* 1955, **180,** Dec., 16, 824–827). This article outlines some recent developments in meeting the increasingly severe requirements for ferritic bolt steels. Mention is made of the properties of a 1% Cr, 0·5% Mo, 0·25% V steel suitable for long-time bolt service at metal temperatures up to 950° F. Further requirements of a bolt steel for temperatures up to 1050° F are examined.—M. D. J. B.

The Manufacture of Watch Springs. (*Machinery*, 1955, **87,** Dec., 30, 1508–1517). The principal stages in the production of watch springs at the works of Samuel Fox and Co. Ltd., Stocksbridge are described in detail. The testing and inspection of finished springs is also discussed.—M. A. K.

Determination of the Mechanical Properties of Tool Steels. Yu. A. Geller. (*Zavodskaya Laboratoriya*, 1955, **21,** (5), 594–601). [In Russian]. The difficulties involved in testing the mechanical properties of tool steels are discussed and some suitable methods are considered. These include twisting under impact load, ordinary compression, non-uniform all-sided compression, twisting and bending. Special attention is devoted to bend testing, and curves are presented showing the dependence of breaking deflection and deflection at the end of the elastic range on tempering temperature, for a carbon tool steel ; and the effect of hardening temperature on the strength and deflection of an alloy hypereutectoid tool steel and on the strength of a high-speed steel.—S. K.

Nickel-Copper Low-alloy Steels. T. N. Armstrong and J. W. Crossett. (*INCO Magazine*, 1955, **26,** Oct., 12–17). Composition, properties, and corrosion resistance are tabulated and uses illustrated.

Progress Reports of Investigation of Railroad Rails and Joint Bars. R. E. Cramer and R. S. Jensen. (*University of Illinois Bulletin*, 1955, **52,** May, No. 66). **Investigations of Failures in Control-cooled Railroad Rails.** 3–11. Causes of failure of 49 rails are given, with length of service and laboratory tests on welded rail bonds. **Thirteenth Progress Report of the Rolling-load Tests of Joint Bars.** 12–25. **Thirteenth Progress Report on Shelly Rail Studies.** 25–30. An account of tests on chrome–vanadium and on high-silicon rails, with photographs of failures.

New Metallurgical Laboratories at the Newton Works of Garringtons Ltd. (*Metal Treatment and Drop Forg.*, 1955, **22,** Oct., 441–444, 448). The functions and facilities of the recently opened new Garrington laboratories are described. Metallurgical control and service to the forging, blade, and finished products divisions of the works are their main purposes and they have a total floor area of 6000 ft². The main equipment of the metallurgical, testing, chemical, metallographic, photographic, heat-treatment and pyrometry department is described.—P. M. C.

METALLOGRAPHY

Use of Micro-Autoradiography in the Study of the Redistribution of Chromium during Diffusional Annealing. I. E. Bolotov and M. I. Gol'dshtein. (*Zavodskaya Laboratoriya*, 1955, **21,** (7), 828–830). [In Russian]. The application of the contact radiographic method for finding the distribution of chromium in a steel after various treatments is described. Cr^{51} was used as the tracer, being introduced as the oxide together with aluminium into the molten steel (0·40% C, 0·58% Mn, 0·24% 5% Si 2·4 Cr, 0·13% Ni, 0·012% P, 0·30% S).Sections were prepared from the 600 g ingot and annealed at 1200, 1300 and 1400° C for various times. After polishing, contact autoradiographs were taken. The original heterogeneity of the chromium distribution was appreciably decreased by annealing for 5 h at 1300° C or 1 h at 1400° C.

A High Frequency Method for Metallographic Investigations on Magnetic Alloys. F. Fraunberger. (*Z. Metallkunde*, 1955, **46,** Oct., 749–751). A method is described which, although originating from a purely magnetic question, appears suitable for investigating a number of metallographic problems. The apparatus is described, and two examples of its use are given.—L. D. H.

Apparatus and Attachment for the Electrolytic Separation of Carbides from Steel. N. I. Rodionova. (*Zavodskaya Laboratoriya*, 1955, **21,** (6), 746). [In Russian]. Apparatus for the simultaneous anodic solution of four steel specimens and separate collection of their carbides and non-metallic inclusions is described.—S. K.

Alloy Carbides Precipitated during the Fourth Stage of Tempering. An Electron Microscopic Examination. K. Kuo. (*J. Iron Steel Inst.*, 1956, **184,** Nov., 258–268). [This issue].

Physical Properties of Interstitial Phases. G. V. Samsonov. (*Doklady Akad. Nauk S.S.S.R.*, 1953, **93,** (4), 689–692). The borides, carbides, and nitrides of transition metals are described.

New Applications of Electron Chemistry in Metallurgy. A. Roos. (*Chim. Ind.*, 1955, **74,** July, 65–70). The properties of metals and alloys is considered in relation to their atomic structure.—B. G. B.

Thermodynamic Analysis II: The Heat Content Curve of a Substance from a Single Calorimetric Test. W. Oelsen, K. H. Rieskamp and O. Oelsen. (*Arch. Eisenhüttenwesen*, 1955, **26,** May, 253–266). The fundamental concepts and objects of the procedure are introduced and the experimental method described. Determinations are instanced of the heat of fusion of tin, bismuth, cadmium, lead, indium, thallium, zinc, and aluminium, of the heat of transformation of thallium, of the heat content and heat of transformation of a soft iron in the region of 25° to 1050°, of the heat contents of lead, cadmium, and a lead-rich alloy of heat content curves for an alloy steel containing 0·96% carbon, of the heat content of an iron-phosphorus alloy containing 1% phosphorus, of the heat content and specific heat of nickel, and of the heat of transformation of an iron–nickel alloy containing 15% nickel.—A. C.

Solution of Carbon in Liquid Iron. O. Dahlke and O. Knacke. (*Arch. Eisenhüttenwesen*, 1955, **26,** July, 373–378). The rate of solution of solid carbon in liquid iron was determined at 1550 and 1590°. Values calculated according to Nernst's theory were compared with the experimental results. A model test was made on the solubility of benzoate in water in order to compare the rates of solution with mechanical stirring and gas-blown convection. Reference is made to the similarity between the solution of carbon in liquid iron and the solution of solids in water. Conclusions of practical interest are drawn from the experiments.—A. C.

Effects of Addition Elements on the Polymorphism of Iron in the Light of Atomic Considerations. K. Schubert. (*Arch. Eisenhüttenwesen*, 1955, **26,** May, 299–306). The Wever rule and earlier attempts to explain it are discussed, followed by the position-correlation of the outer electrons in α- and γ-iron and the effect of addition elements on the position-correlation of iron. Titanium and cobalt alloys are considered.—A. C.

Slip-Band Extrusion. E. A. Calnan and B. E. Williams. (*J. Inst. Metals*, 1955–56, **84,** Apr. 318). Electron micrographs of copper indicate the occurrence of slip-band extrusion in simple tensile deformation. It is suggested this may be due to slip on parallel planes in different directions.—B. G. B.

Investigation of Segregation In Cast Irons by Radiographic Techniques. J. Cohen, E. Hall, L. Leonard, and R. Ogilvie. (*Non-Destructive Test.*, 1955, **13,** Mar.–Apr., 33–34). A technique for the more effective utilization of microradiography in the metallographic study of metal structures is described and illustrated. Satisfactory contrast and resolution is maintained in prints of ×200 magnification by photographing through a petrographic microscope and subsequent photographic enlargement.—P. M. C.

Device for Controlling Forgings with a Metallographic Microscope. V. E. Pronin and P. A. Averchenko. (*Zavod-*

skaya Laboratoriya, 1955, **21**, (7), 870). [In Russian]. A very brief account is given of a simple arrangement which enables polished sections on large forgings to be examined with a horizontal metallographic microscope.—S. K.

Microscopic Information from Carbide Separations from Supersaturated α-Iron. H. J. Seemann and U. Hintzpeter. (*Arch. Eisenhüttenwesen*, 1955, **26**, May, 287–289). Microscopic and hardness examinations were carried out on iron-carbon alloys containing 0·02 and 0·13% carbon after quenching and annealing.—A. C.

The Determination of the Alpha Phase Boundary of the Iron–Nitrogen System by Internal Friction Methods. R. Rawlings and D. Tambini. (*J. Iron Steel Inst.*, 1956, **184**, Nov., 302–309). [This issue].

Observations of Bainite Transformation by Hot Stage Microscope. K. Tsuya. (*J. Med. Lab. Japan*, 1955, **9**, Sept., 186–193). Hot-stage microscope studies of bainite formation revealed coherence of bainite with austenite matrix, surface relief growing, reaching a maximum, and changing in shape with temperature of transformation, the changes being continuous. The hot stage microscope is also described.—J. G. W.

High Resolution Autoradiography. (*Metallurgia*, 1956, **53**, Jan., 48–49). A brief note on the successful use of wet process autoradiography in metallography for resolving particles as small as 1 micron and with an inter-particle distance of less than 10 microns is presented.—B. G. B.

Reagent for Revealing Free Cementite and Phosphorus Segregations in Carbon Steels and Irons. Kh. I. Rabinovich. (*Zavodskaya Laboratoriya*, 1955, **21**, (6), 708–710). [In Russian]. The use of a cold-saturated solution of sodium thiosulphate, slightly acidified by the addition of 1–2 g of sodium or potassium metabisulphite per 100 g of solution, for etching macro- and micro-sections is described. The treatment reveals clearly the presence of free cementite and segregation of phosphorus. Photomicrographs of low-carbon iron, high-phosphorus decarburized pig iron, rimming steel and hypo-eutectic grey iron obtained with the use of the reagent are presented and discussed. The reliability of the reagent has been established independently.—S. K.

Thermodynamic Investigation of Non-metallic Inclusions in Steel. I. H. Sawamura and T. Mori. (*Tetsu to Hagane*, 1955, **41**, Oct., 1082–1090). [In Japanese]. Free-energy equations for the formation of nitrides in steel are derived from equilibrium diagrams and other published data. Equilibrium conditions for formation of nitrides of Al, Si and Fe, between room temp. and the m.p., are calculated for steels of composition C 0·15, Al 0·01 and 0·03, Si 0·5, N 0·005 and Mn <1·5%. Results show that nitrides of Si and, particularly, Al should act as grain-growth inhibitors.

Instrumentation in Crystal Mechanics. A. J. Kennedy. (*Instrument Practice*, 1955, **9**, Nov., 1052–1056). This paper describes devices used for the determination of shear stresses applied to single crystals. Geometric instruments described are those of Bausch, Röhm and Kochendörfer and Kennedy. Profile devices, loaded so that the revolved shear stress on the slip planes remain constant, are discussed in greater detail. The method of computing the profile curve is given, and simplified methods of construction are indicated.—L. D. H.

Method of Measuring the Austenite Grain. I. S. Gaev and V. V. Polovnikov. (*Zavodskaya Laboratoriya*, 1955, **21**, (5), 565–567). [In Russian]. Austenite grain-size determination for characterizing the liability of a given heat of steel to grain-growth is considered. A brief critical review is given of standard methods in general and as applied to several steels, and results obtained by four methods for a steel with 0·38% C and 0·6 % Mn are compared.—S. K.

The Occurence of Sigma Phase in a High-Chromium-Nickel Steel with Particular Reference to the Influence of Silicon. L. Pryce, H. Hughes, and K. W. Andrews. (*J. Iron Steel Inst.*, 1956, **184**, Nov., 289–301). [This issue].

Impurities and Imperfections. American Society for Metals, Oct., 1955. Report of Seminar.

Lattice Vacancies and Interstitials in Metals. H. Brooks. Pp. 1–27. The behaviour of vacancies and interstitial atoms is discussed generally. Their energy of formation is derived, as far as possible, from formal thermodynamic theory, macroscopic physical concepts, and quantum mechanical considerations. Such experimental evidence as is applicable is surveyed. (28 references).

Dislocations. J. C. Fisher. Pp. 28–40. The formation of screw and edge dislocations is described in an elementary way, and the relevance of these concepts in explaining slip, crystal growth, grain boundary structures, polygonization, diffusion and the causes of alloy strength is explained.

Grain Boundaries. Substructures and Impurities. R. W. Cahn. Pp. 41–83. The characteristics of grain boundaries are reviewed, and the segregation of impurities and dislocations, fusion of grain boundaries, and intergranular corrosion are discussed. The modes of formation of sub-granular structures are described; they include cold and hot deformation, recrystallization and phase transformation. (121 references).

Effects of Impurities and Imperfections on Crystal Growth. B. Chalmers. Pp. 84–106. After a review of crystal growth from vapours, the growth of pure crystals from the melt and the origin and role of imperfections are discussed, and finally the effects of impurities on such growth. (24 references).

Impurities and Imperfections in Metallic Diffusion. D. Lazarus. Pp. 107–120. The role of impurities in diffusion is treated by considering the electrostatic effects of excess valency. The interaction of the energy of the screening potential produced with that of neighbouring atoms causes measurable changes in diffusion rates for impurities relative to self-diffusion, and in an impure material relative to a pure one. (15 references).

Role of Structural Impurities in Phase Transformations. D. Turnbull. Pp. 121–144. Crystal formation in condensed systems is considered in the light of dislocation theory. Nucleation in solids is much affected by imperfections and impurities. Rapid rates of zone formation are attributed to the effects of quenched-in vacancies or dislocation channels. (52 references).

Effects of Impurities and Imperfections on Mechanical Properties. E. R. Parker and J. Washburn. Pp. 145–161. The effects of dislocations etc., are considered in relation to work-hardening, creep, yield and other phenomena. (14 references).

Influence of Impurities and Imperfections on the Electrical Properties of Metals. J. S. Koehler. Pp. 162–169. The effects of point imperfections, dislocations, stacking faults, grain boundaries and precipitates on such properties as resistivity, the Hall coefficient and thermo-electric behaviour are discussed. (22 references).

Structure-dependent Chemistry of Metal Surfaces. W. D. Robertson. Pp. 170–185. Intergranular penetration, stress-corrosion cracking, and similar phenomena in pure metals and alloys are related to dislocation effects, boundary structures, reaction in slip clusters, etc. (15 references).

Effects of Impurities and Imperfections in Semi-conductors. J. A. Burton. Pp. 186–199. (59 references).

Vacancies and Alkali Halide Crystals. R. Maurer. Pp. 200–212. (11 references).

Radiation Disarrangement of Crystals. F. Seitz and J. S. Koehler. Pp. 213–221. The damage effects produced in crystalline solids by light charged particles (electrons, protons, deuterons, α-particles) are considered, with details of the effects in germanium and copper. (16 references).—K. E. J.

Statistical Analysis of Structures with Spherical Grains. A. G. Spektor. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 193–197). [In Russian]. It is shown that parameters for comparing structures with spherical-type grains can be obtained without complete distribution studies. General equations are given connecting the sums of the degrees of sphericity in a solid structure with the sums of the corresponding diameters of circular sections in a plane section and the chord-lengths in an intersecting straight line. The mean diameter of the grain sections is determined only by the mean diameter of the solid grains and their distribution scatter, and the scatter of section-diameter distribution depends on the scatter and asymmetry of distribution of grain diameters.—S. K.

Study of the Phenomena of Polygonisation and their Practical Applications. J. Talbot. (*Chim. Ind.*, 1956, **75**, Mar., 509–518). The development of micrographic and radiocrystallographic techniques have made it possible to observe this physical state of metals and techniques are described. The conditions of formation of polygonized metals are explained. The significance of the polygonized state in the study of the recrystallization of pure metals is

reviewed and the importance of traces of impurities in the process is stressed.—B. G. B.

Models of Metal Structure. Sir L. Bragg. (*Proc. Roy. Inst.*, 1955, **35**, Part 4, 844–852). The use of models of metal structures to elucidate the properties of metals are discussed. The growth of crystals to form a screw dislocation and 'slip' in crystals are particularly considered.—B. G. B.

Crystal Growth and Lattice Imperfections. C. Elbaum. (*Canad. Metals*, 1955, **18**, Dec., 36–40). A review of theories of crystal growth is presented. The importance of screw dislocations in promoting crystal growth from solutions or vapours is explained.—B. G. B.

Defects in Crystalline Solids. (*Report of the Conference held at the H. H. Wills Physical Laboratory, University of Bristol, July*, 1954. *Published by the Physical Society*). This conference was organized by the University of Bristol in co-operation with the International Union of Physics, in particular the Commission of that Union for the Physics of the Solid State, and also with the Institute of Physics and the Physical Society. None of the papers was concerned specifically with iron and steel, but many of the ideas and results presented are of fundamental importance in the study of metals generally. The most relevant papers are as follows:—

Types of Dislocation Source. B. A. Bilby. (124–133). The Frank-Read type of dislocation source, or "plane" source, is distinguished from those for which the Burgers vector of the pole dislocation does not lie in the sweeping plane. This type is termed a "cone" source. An estimate is made of the relative numbers of these two types existing in the face centred cubic lattice: these appear to be of the same order of magnitude. The problem of the dislocations formed near an indentation is specially treated.

Crystal Growth and Lattice Defects. W. Dekeyser. (134–142). A review of recent work at the University of Ghent, covering metal crystals, the polytypism of micas and long-chain compounds (such as monocarboxylic acids and *n*-alcohols), substructures on ZnS crystals and spiral pits. Work has also been carried out on the reverse process to growth, that of dissolution and etching.

The Electrical Effects of Dislocations in Germanium. W. T. Read, jun., and G. L. Pearson. (143–152). Experimental results to date indicate that dislocations have a single acceptor type energy level near to, or just above, the middle of the energy gap. A theory is presented which attempts to treat the observations by viewing the dislocation as a line of closely spaced acceptors. The theory is applied to such problems as the conductivity parallel to the dislocations, the distortion of the current streamlines by the dislocations, and the effect on mean free path of thermal and dislocation scattering. Some theoretical predictions are made which are the subject of experimental investigation.

Dislocation in Face-Centred Cubic Lattices. N. Thompson. (153–158). Where both types of possible stacking fault are present, the boundary between the regions is a dislocation which will move fairly freely if the faults have different energies until a node is reached. The energy of the dislocation line tends to pull in the boundaries in which it ends, forming a "constriction." The degree of this contraction is discussed, and the arguments extended to the behaviour and the energies of jogs in dislocations.

Hexagonal Networks of Dislocations. F. C. Frank. 159–168). An examination of the geometry of the different possible types and arrangements, and of their expected frequency.

An Experimental Study of Dislocations in Aluminium-Copper Alloys by Means of Precipitation. H. Wilsdorf and D. Kuhlmann-Wilsdorf. (175–186). Preferred precipitation in slip lines and dislocations has been examined in aluminium containing 1·2, 2·2 and 4·8% copper The evidence suggests that the nuclei are formed in the dislocations themselves, the precipitates in any dislocation-section having a common orientation and being densely spaced. The traces observed in undeformed metal appear to be direct indicators of the dislocation network.

Structure and Anisotropy of Diffusion in Grain Boundaries. R. Smoluchowski. (197–202). The diffusion of silver in a grain boundary of copper has been examined as a function of the angle between the direction of diffusion and the common cubic direction for various angles of disorientation. The highest rate of diffusion was in the common cubic direction. The highest anisotropy occurs at the lowest angles at which grain boundary diffusion is observed, and decreases to zero at the highest angle of disorientation. The results are compared with the self-diffusion of iron along grain boundaries, and some differences discussed.

Diffusion Short Circuits and their Role in Precipitation. D. Turnbull. (203–211). A discussion of the role of dislocations and boundaries in increasing the apparent diffusion and precipitation rates in metals.

Stored Energy and Lattice Defects in Cold-Worked Metals. W. Boas. (212–221). The experiment consists essentially of measuring the difference between the powers required to maintain an annealed and a deformed specimen at the same temperature as an enclosure heated at a constant rate. Density and resistivity changes were also measured. It is concluded that almost all the energy stored in copper is due to dislocations, but that vacancies make an important contribution to that stored in nickel.

Radiation Disarrangement of Crystals. J. S. Koehler and F. Seitz. (222–231). The possible kinds of imperfections produced by irradiation are discussed, as well as the observed annealing processes, both thermal and those resulting from irradiation.

Recent Experiments at Harwell on Irradiation Effects in Crystalline Solids. R. A. Dugdale. (246–251). The effects of bombardment on boron nitride (change of lattice parameter), and the nature of the subsequent recovery, are reported. The resistance changes in pure metals, tungsten, molybdenum, and platinum, and in the alloy Cu_3Au are briefly summarized.

Stacking Faults in Close-Packed Lattices. A. Seeger. (328–339). A review of knowledge of the energies of stacking faults in various face-centred and hexagonal close-packed metals. A division of close-packed metals into two groups, the noble metals and cobalt in one group and multivalent metals and the nickel-group in the other, with respectively low and high fault energies corresponds with a division according to whether dislocations in close-packed glide planes are widely extended or not. The differences should also show up in the various mechanical properties.

Activation Energy Problems Associated with Extended Dislocations. G. Schoeck and A. Seeger. (340–346). The energy of constrictions (the points in an extended dislocation where two partial dislocations are brought together) are calculated for aluminium and copper. The results are applied to the problem of cross-slip of screw dislocations in face-centred-cubic lattices.

Sub-Structures and Networks of Dislocations in Face-Centred Cubic Metals. T. Suzuki and T. Imura. (347–358). Observations made on the etch-patterns obtained on aluminium and Al-Mn alloys reveal regular dislocation arrays of hexagonal form. The formation of these networks, and the effects of alloying elements, and of annealing, are discussed.

The Surface Topography of Diffusion Couples. R. S. Barnes. (359–368). Microscopic and X-ray examination of the free surfaces of Cu-Ni diffusion couples shows that voids which form near to the interface in the faster diffusing metal produce pits in the surface when evaporation occurs on annealing. Steps occur at grain boundaries and the grain surfaces are rippled. It is suggested that this rippling is caused by the insertion of a series of adjacent parallel $\{110\}$ planes on the nickel-rich side, and by their elimination on the copper-rich side. The climb of the edge dislocation configuration could produce such an effect.

Jogs in Dislocation Lines. A. Seeger. (391–401). The geometrical properties of such jogs are investigated, and it is shown that those formed by diffusional processes will, in general, have different properties from those formed as a result of dislocation intersection. The cases of face-centred-cubic, hexagonal close-packed and NaCl lattices are considered separately. The application of the ideas to high-temperature creep is briefly discussed.—A. J. K.

Appearance of Twin Crystals of Deformation and the Mode of Fracture of α-Iron. H. Buchholtz, F. Braumann, and A. Eier. (*Arch. Eisenhüttenwesen*, 1955, **26**, June,

337–344). Impact tests were carried out on technically pure iron, basic Bessemer steel containing 0·009% C, 0·02% Si, 0·21% Mn, 0·9% P, and 0·01% Al, open-hearth steel containing 0·11% C, 0·08% Si, 0·43% Mn, 0·031% P, and 0·03% Al, and a chrome vanadium steel containing 0·11% C, 0·33% Si, 0·30% Mn, 1·39% Cr, and 0·32% V in unaged and aged conditions. The effect of the rate of stressing (50–4600 mm/sec) on the temperature of transition from ductile to brittle fracture was observed, as was the transition from fracture exhibiting twin crystals of deformation to fracture not exhibiting them. The tests were carried out under uni-axial tension at temperatures from 80 to −195°. The authors discuss the significance of minute cracks with respect to the onset of brittle fracture.—A. C.

Some Special Features of Martensite Transformation as Shown by Metallographic Analysis. A. N. Alfimov and A. P. Gulyaev. (*Izvest. Akad. Nauk SSSR, Otdelenie Tekn. Nauk*, 1954, (4), 93–99). [In Russian]. Metallographic investigation of martensite transformation in steel specimens (1·0–1·6% C; 2·6–3·0% Mn) with a coarse grain austenite structure during cooling in liquid nitrogen is described. In the course of the transformation deformation and division of initially formed martensite crystals and their displacement from the initial positions was observed. During this process spaces between martensite fragments are filled with austenite. Thus as a result of martensite transformation, austenite is strongly deformed which may explain the autoinhibition of the martensite reaction.—V. G.

Transformations During Tempering High-Speed Cutting Steel. Yu. A. Geller. (*Izvest. Akad. Nauk, SSSR, Otdelenie Tekn. Nauk*, 1954, (5), 73–80). [In Russian]. Transformations taking place during tempering of high speed cutting steel were investigated using phase analysis and measurements of physical properties. A decrease in hardness after tempering at 200–400° C is due to separation of carbide of the cementite type cause by a decrease of carbon content in martensite. The phenomena of the secondary hardness after tempering at 500–600° C is caused mainly by dispersion hardening due to the separation of vanadium and to some extent, tungsten carbides. The dispersion hardening takes place mainly in the martensite structure as part of the alloying elements, particularly tungsten, remain in a solution retaining in it a certain amount of carbon. The influence of tungsten and vanadium on transformations and secondary hardness is discussed. The necessity of alloying with both the above elements is stressed. The influence of the transformation of residual austenite on secondary hardness is less important.—V. G.

Effects of Nucleation Site Upon Precipitate Morphology. H. I. Aaronson. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 47–56). Two effects on pro-eutectoid ferrite morphology during transformations in plain carbon steel are reported. The structure of the austenite grain boundary can determine whether a ferrite crystal is a grain-boundary allotriomorph or a primary Widmanstätten sawtooth or sideplate. A base layer of grain-boundary allotriomorphs may determine whether secondary sideplates or sawteeth will grow, and their orientation. Both effects are explained qualitatively. (26 references).—K. E. J.

The Stabilisation of Austenite. S. G. Glover and T. B. Smith. (*Institute of Metals Monograph and Report Series* 1955, No. 18, 265–276). The thermal stabilization of austenite after partial transformation to martensite has been investigated in a steel containing 1% C and 3% Mn. It produced a temperature lag, on subsequent cooling, before transformation began again, but this was accelerated. This lag increased as the amount of pilot transformation increased. Stabilization may be associated with the first stage of tempering of martensite. (37 references).—K. E. J.

The Bainite Reaction in High-Carbon Steels. O. Krisement and F. Wever. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 253–263). The influence of the precipitation of carbide in austenite on the bainite reaction has been studied, and confirmatory evidence is adduced. For higher carbon concentrations, bainitic ferrite can form adjacent to the surface of a growing carbide particle, but not in the austenitic matrix of average carbon concentration. Here the bainitic structure is generated by a reaction involving alternating pptn. of carbide lamellae and ferrite plates. (18 references).—K. E. J.

Crystal Geometry of the Austenite–Martensite Transformation. T. Ll. Richards and W. T. Roberts. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 193–207). The transformation is considered to be equivalent to a combination of a simple Bain mechanism and a body rotation. By matrix analysis, relationships between corresponding planes in each phase are obtained. The possible shear modes of the transformation are derived by application of the principle of the unextended cone. (12 references).—K. E. J.

Homogeneous versus Heterogeneous Nucleation in the Martensitic Transformation. L. Kaufman and M. Cohen. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 187–191). Determinations on a series of iron-nickel alloys show that the M_S point occurs at progressively lower temp., approaching 0° K as the nickel content is increased. Homogeneous nucleation, which precludes M_S temp. $<\sim$ 120° K in these substitutional alloys, is not operative, and the results accord with the concept of heterogeneous nucleation at preferred sites.—K. E. J.

The Nucleation Problem in Martensite. M. A. Jaswon. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 173–185). The dislocation-source theory of martensite nucleation is outlined, with reference to many examples of the martensite reaction in varying systems, and is compared with the classical embryo theory of Fisher, Hollomon and Turner. In the present state of knowledge, the latter, although involving many assumptions, can give useful results, particularly of quantitative nature. (48 references).—K. E. J.

Martensitic Transformations. B. A. Bilby and J. W. Christian. (*Institute of Metals Monograph and Report Series*, 1955, No. 18, 121–172). A definition of martensitic reactions should be based on experimental observation of a change of shape in the transformed regions. Available crystallographic and kinetic data for all transformations of this type are reviewed, and an account is given of recent theories of the crystallography of martensite. The nucleation process, and the possible roles of dislocations in the transformations, are discussed. (166 references).—K. E. J.

Sigma-phase Nucleation and other Transformations During Diffusion in the Iron–Chromium System. H. J. Goldschmidt. *Institute of Metals Monograph and Report Series*, 1955, No. 18, 105–119). The progress of diffusion in powder compacts under various conditions has been studied by X-ray analysis and microradiography. The rate of solid-solution formation is determined. Some features observed are attributed to incipient σ formation in the α lattice, or to a retarding influence of the $\gamma \rightarrow \alpha$ transformation on diffusion. The Kirkendall effect is pronounced. A threshold chromium content is required to initiate diffusion. The σ phase can form metastably at 1100° C. (13 references).—K. E. J.

Formation of Coarse-Grained Structure in Medium-Carbon Steel Sheet. K. A. Koksharov. (*Stal'*, 1955, (5), 458–463). [In Russian]. In the investigation described, the formation of coarse-grained structures in low-carbon (0·16, 0·11, 0·08% C) steel was studied, surface decarburization of the test-pieces being avoided. Coarse-grained ferrite was found to be formed by heating in the range 650–900° C after previous rapid cooling from high temperatures in the critical range of the $\gamma \rightarrow \alpha$ transformation. The volume changes in the $\gamma \rightarrow \alpha$ transformation produce work hardening of the ferrite grains leading to their recrystallization on subsequent heating. For this work hardening to occur the austenite transformation must be displaced into the temperature range where the relaxation and recrystallization processes are very slow, which can be achieved by rapid cooling (of the order of 100° C per sec). The ferrite recrystallization in an oxidizing atmosphere is accompanied by intensive decarburization.—S. K.

The Kinetics of the Martensitic Transformation in a Ferronickel. J. Philibert. (*Compt. Rend.*, 1955, **240**, Jan. 31, 529–531). The effect of very small amounts of carbon and nitrogen on the martensitic transformation in a ferronickel is very marked. With the addition of either of these impurities, a ferronickel can be stabilized under the same conditions as with carbon steel. The true character of germination is shown since the transformation is isothermal and not marked by the formation of repeated chains of martensite.—G. E. D.

Toughness Without Tempering. R. H. Aborn. (*Metal Progress*, 1955, **68**, Dec., 112–117, 154). The high toughness of quench hardened low-carbon steels is associated with the high temperature formation of martensite and the subse-

quent tempering which occurs during quenching. A number of examples of the structures obtained are given and the mechanism of the change is discussed. The properties and application of these steels are reviewed.—B. G. B.

Kinetics of Order–Disorder Transformations. G. J. Dines. (*Acta Met.*, 1955, **3,** Nov., 549–557). A simple theory based on chemical rate theory is presented and shown to be in agreement with the experimentally known qualitative behaviour of order–disorder systems.—A. D. H.

Effect of Temperature of Austenite Formation on Transformation and Hardening of Structural Steel. A. Rose and W. Strassburg. (*Stahl u. Eisen*, 1955, **75,** Nov. 3, 1472–1480). Investigations were carried out on a series of case-hardening and age-hardening steels as well as some high-speed tool steel. In the case of transformation from single-phase initial states, the ferrite and pearlite transformations were slowed down with increasing temperature of austenite formation, while the intermediate transformation was unaffected. In the case of transformation from polyphase initial states, change in the temperature of austenite formation was accompanied by change in the composition of the solid solution transformed, and by displacement of the intermediate transformation. The effects on hardening properties are discussed.—A. C.

Incubation Period in the Martensitic Transformation. J. Philibert. (*Compt. Rend.*, 1954, **239,** Dec. 8, 1634–1636). The results of an isothermal dilatometer study of the martensitic transformation at low temperatures on a hypereutectic steel (1·55% C, 2·55 % Cr) are discussed. The period of incubation preceding the isothermal transformation varies with the temperature and the amount of martensite formed depends on the speed of cooling.—G. E. D.

Intermediate Stages of Transformation of Manganese Steels. W. Dahl, W. Jellinghaus, and E. Houdremont. (*Arch. Eisenhüttenwesen*, 1955, **26,** Oct., 589–597). Four steels (0·6–1·2% C and 1·9–4·1% Mn) were investigated for the effect of pre-orientation at the temperature of the lower intermediate stage on the transformation at the upper intermediate stage. The shift of the martensite point in 2% Mn steel is referred to, and measurements of magnetic and electrical properties are compared. The significance of the experimental results is discussed.—A. C.

On the Theory of Phase Transformation in Steel. A. P. Gulyaev and V. M. Zalkin. (*Izvest. Akad. Nauk. SSSR, Otdelenie Tekn. Nauk*, 1955, (7), 93–95). [In Russian]. Kinetics of the pearlite-austenite transformation on continuous heating were investigated. Specimens were heated by passing an electric current. On reaching the required temperature they were quenched in water. It was found that the temperature of the beginning of transformation is independent of the rate of heating. The transformation takes place in a temperature interval the width of which increases with increasing heating rate. At a sufficiently high heating rate, the part of the transformation which takes place isothermally may be absent. —V. G.

On the Kinetics of the Isothermal Formation of Austenite. A. P. Gulyaev and V. M. Zalkin. (*Izvest. Akad. Nauk, SSSR, Otdelenie Tekn. Nauk*, 1955, (6), 114–118). [In Russian]. Kinetics of isothermal transformation of steel U-8 with the initial structure of plate-like pearlite was investigated at soaking temperatures of 745, 755 and 770° C. Heating of the specimen was done by electric current at a rate of 60°/sec. On the basis of results obtained curves representing rates of transformation at various temperatures as well as the influence of rate of heating on the kinetics of this transformation were prepared.—V. G.

On the Intermediate Transformation of Supercooled Austenite. L. I. Kogan and R. I. Entin. (*Izvest. Akad. Nauk, SSSR, Otdelenie Tekn. Nauk*, 1955 (1), 67–79). [In Russian]. Experimental data obtained in this investigation indicated that the transformation of austenite in the intermediate region consists of processes of the redistribution of carbon by diffusion and γ—α martensite transformation. The differences in the kinetics of this transformation in various steels can be explained by differences in the velocity of diffusion of carbon and by various conditions of the formation of metastable phases during the transformation of austenite (enrichment of austenite in carbon or the formation of cementite).—V. G.

The Existence of an Order–Disorder Transformation in Iron–Chromium Alloys of About Equiatomic Composition. P. Bastien and G. Pomey. (*Compt. Rend.*, 1954. **239,** Dec. 8, 1636–1638). Thermal magnetometric and dilatometer analyses show that for iron–chromium alloys containing 43–70% chrome, there are two critical temperatures each with a precise Curie point. This is not apparent if the structure is studied by *X*-ray diffraction. The final structure of the alloy is influenced by the annealing temperature and the speed of cooling. The existence of two structures for a given alloy is submitted as evidence of an order–disorder transformation.—G. E. D.

General Nature of the $\alpha \rightleftharpoons \sigma$ Transformation of Iron–Chromium Alloys. P. Bastien and G. Pomey. (*Compt. Rend.*, 1954, **239,** Dec. 20, 1797–1799). The study of the $\alpha \rightleftharpoons \sigma$ transformation of Fe–Cr alloys shows that the $\alpha \rightleftharpoons \sigma$ changes begins with a very small number of nuclei, the transformation mainly continuing as a result of the growth of σ grains. The two phases can be identified microscopically by making use of the differences between their hardnesses and the brittleness of the σ phase.—G. E. D.

On the Cause of the Stabilization of Austenite in the Martensitic Transformation. J. Philibert. (*Compt. Rend.*, 1955, **240,** Jan. 10, 190–192). During the martensitic transformation of a ferronickel containing traces of carbon and nitrogen, a weak stabilization of the austenite can be seen. After prolonged treatment to remove the carbon and the nitrogen, this stabilization completely disappeared, proving that it is due to the presence of these two elements.—G. E. D.

Dilatometric Study of the Heating of Carbonyl Iron under Isothermal Conditions. G. Cizeron and P. Lacombe. (*Compt. Rend.*, 1955, **240,** Jan. 24, 427–429). The heating of carbonyl iron is studied in all cases from the A_3 transformation point by dilatometry under isothermal conditions and for periods of prolonged heating. The interpretation of isothermal shrinkage curves enables the heats of activation to be measured at different stages of the heating and the part played by the mechanisms of diffusion in the mass and at the joints to be shown.—G. E. D.

The Martensite Transformation. A. Michel. (*Bull. Cercle, Etudes Métaux*, 1955, **6,** June, 345–382; Sept., 385–414). A comprehensive review of existing knowledge and theories of the martensite transformation in steels is presented. (Over 50 references).—B. G. B.

A Study of the Final Stages of the Austenite to Martensite Transformation in SAE 1050 Steel. M R. Meyerson and S. J. Rosenberg. (*J. Res. Nat. Bur. Stand.*, 1955, **55,** Sept., 177–181). The austenite–martensite transformation curves in the temperature range M_s to −320° F has been established for two steels of this type. No significant effect of austenitizing temperature or austenite grain size on the rate of formation of martensite was observed at temperatures less than 100° below the M_s. Cooling rate had no effect on the transformation. Even at −320° F 1% retained austenite was present.

Effect of Elastic Strain on the Formation of Martensite. A. Kochendörfer and H.-G. Müller. (*Arch. Eisenhüttenwesen*, 1955, **26,** May, 291–298). The martensite transformation in single crystals of steel containing 0·23% carbon and 26% nickel was investigated. Crystalline strain and slip line formation with martensite formation were observed, as were martensite transformation without external stress, and under tensile and shear stress.—A. C.

Effect of External Tension in Martensite Formation. W. Schmiedel and H. Lange. (*Arch. Eisenhüttenwesen*, 1955, **26,** June, 359–363). The process of formation of martensite is discussed. The authors describe experiments to find the effect of tension on the formation of martensite in steel containing 18% Cr and 8% Ni, and discuss the significance of their test results.—A. C.

Kinetics of Transformation of the σ-Phase in 48% Cr Iron–Chrome Alloy. E. Baerlecken and H. Fabritius. (*Arch. Eisenhüttenwesen*, 1955, **26,** Nov., 679–686). Magnetic investigations were carried out on the α–σ and σ–α transformation in an iron-chrome alloy containing 48% Cr. Equations are given for the progress of the α–σ transformation with time, and an account of paramagnetic investigations of the σ phase is added.—A. C.

The Formation of Austenite in Plain Carbon Steels at High Heating Rates. R. A. Huggins, H. Udin, and J. Wulff. (*Welding J.*, 1956, Jan., 18s–26s). Thin strips were heated rapidly by passing electric current longitudinally through them. The instantaneous temperature was measured by means of a lead sulphide photoconductive cell. The temperature–time cycle

was photographed on a cathode-ray oscillograph. It was found that changes in heating rate within the range studied (2000–20,000° C/sec) have no appreciable effects. Prior structure was found to be very significant, both with regard to the manner and the rate at which austenite formed.

Heterogeneous Nucleation of the Martensite Transformation. R. E. Cech and D. Turnbull. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Feb., Section 2, 124–132). The authors describe experiments on powders of Fe–Ni alloy which indicate that martensite transformation starts on heterogeneous nucleation sites. The nature of these sites is hypothesized and a mechanism for the burst phenomenon in Fe–Ni alloys is put forward qualitatively.—G. F.

Furnace for Studying the Structure of Alloys by Heat Treatment in a Vacuum. I. I. Pyasetskiĭ and I. V. Salli. (*Zavodskaya Laboratoriya*, 1955, **21**, (2), 243). [In Russian]. A vacuum furnace is described with which the structure of a metal surface during crystallization from the liquid state can be studied. A photomicrograph of a hypereutectoid steel surface is shown.—S. K.

Equilibrium Diagram for the Iron–Iron Phosphide Fe_2P–Tungsten Phosphide WP System. R. Schneider and R. Vogel. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 483–490). The equilibrium diagram shows a ternary iron-rich solid solution in equilibrium with tungsten phosphide. Three ternary peritectic transformations and one ternary eutectic reaction occur.—A. C.

The Structure of Hard and Refractory Materials. H. Nowotny. (*Chim. Ind.*, 1955, **74**, Aug., 227–242). The properties of metallic carbides, silicides, nitrides and borides alone or in mixtures are considered in detail. (38 references).

The Iron-Cobalt-Vanadium System. I. Formation with Retarded α/γ Transformation. W. Köster and H. Schmid. (*Arch. Eisenhüttenwesen*, 1955, **26**, June, 345–353). The authors discuss thermal, dilatometric, magnetic, microscopic, and X-ray investigations of the formation of iron–cobalt–vanadium systems, the determination of fusion equilibria and transformations, and the indication of phase-spaces in the solid form from isothermal sections at 1000, 1200, and 1300°.

The Iron-Cobalt-Vanadium System. II. Development of Equilibria Between α/γ Mixed Crystals. W. Köster and H. Schmid. (*Arch. Eisenhüttenwesen*, 1955, **26**, July, 421–425). The authors describe the changes in structure of the iron–cobalt–vanadium system over an extended period of up to one year. The equilibrium of α- and γ-mixed crystals, and the variation, with annealing time and temperature, of the hardness, resistivity, and coercivity of the γ-alloy are discussed.—A. C.

Thermodynamic Properties of Solid Fe–Au Alloys. L. L. Seigle. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Feb., Section 2, 91–97). Measurements of thermodynamic properties of Fe–Au alloys between 800–900° C, by the galvanic cell method, show a positive deviation from Raoult's Law and a large excess entropy of mixing, both attributable to lattice distortion. Based on the data obtained, some changes in the Fe–Au phase diagram are suggested.—

A Microstructural Study of the Carbide Phase Changes on Tempering a Molybdenum Steel with 0·11% C and 2·14% Mo. K. Kuo. (*Jernkontorets Ann.*, 1956, **140**, 1, 24–46). [In English]. Microscopic and X-ray diffraction studies were made of the structural changes accompanying the conversion of Fe_3C into Mo_2C on tempering. The electron microscope provided more detailed information than did other methods. An account is given of the formation and disappearance of Fe_3C, the growth of Mo_2C and of changes in ferrite orientation above 650° C.—G. G. K.

The Calcium Oxide–Wüstite System. V. Cirilli and A. Burdese. (*Proc. of the International Symposium on the Reactivity of Solids, Gothenburg*, 1952, 1954, 867–879). [In English]. The system has been studied by determining the reduction equilibria at different temperatures and the relations between the solid phases dicalcium ferrite, wüstite, calcium oxide, and iron defined. The diagram is given for the lower oxidation limit. Below 1070° C lime–wüstite solid solutions are metastable unless the gaseous composition is favourable.

CORROSION

Symposium on Corrosion. (*Papers Presented at a Conference held in Melbourne University*, Nov. 28–Dec. 2, 1955). This symposium was organized by the Melbourne Division of the Institution of Engineers, the Melbourne Branch of the Asutralian Institute of Metals, the Society of Chemical Industry (Victoria) and other Australian Engineering and Scientific bodies. The following papers were presented :

Mechanism of Corrosion and its Prevention. A. F. Dunbar and H. A. Stephens. (34 pp.) The authors describe the electrochemical basis of corrosion and then discuss the factors causing the formation of anodes and cathodes and the factors modifying the corrosion rate, these latter including notes on polarization, movement between electrode and electrolyte, rate of supply of oxygen, stress, temperature, micro-organisms and the composition and structure of the metal or alloy. The corrosion equilibruim diagram for iron is dealt with. In the latter part of the paper the authors consider corrosion prevention in terms of electrochemical methods, alloying, and protective coatings. (58 references).

The Oxidation of Metals. T. Mills. (15 pp.) The author discusses how the physical and electrical properties of the scale affect the rate of growth of oxides on metals and then introduces Wagner's concept and the Hoar-Price derivation of Wagner's parabolic equation. Examples of how Hauffe varied the oxidation resistance by alloying additions which alter the conductivity are given. The logarithmic types of growth laws and those derived by Mott for very thin films are also dealt with. (32 references).

Some Aspects of the Kinetics of Corrosion Reactions. G. M. Willis. (13 pp.) The electrochemical aspects only of corrosion rates are considered on the basis of polarization curves. The exchange current is used as a measure of the polarizability of an electrode reaction, and the anodic behaviour of metals and the cathodic reduction of oxygen are discussed. The influence of adsorbed anions on electrode reactions is surveyed, and results are presented which show that ions such as cyanide, bromide and iodide retard the reduction of oxygen. (33 references).

Corrosion and Stress. U. R. Evans. (27 pp.) The author reviews first the causes of localized corrosion and then the changes leading to mechanical or electrochemical sensitivity at grain boundaries. It is pointed out that in some cases a small amount of chemical or electrochemical destruction at the strong bridges joining the grains may suffice to allow grains to be pulled apart instead of the material exhibiting normal ductile behaviour. In other cases (especially where the path of the crack is transgranular) there seems to be a steady electrochemical eating away through the cross-section of the specimen. Sometimes the advance of a crack can be arrested by shutting off oxygen or applying cathodic protection. The author then considers the effect of prior straining upon corrosion and refers to "season" cracking. Layer corrosion, hydrogen blistering and cracking which can themselves produce stress are discussed. Finally the caustic cracking of boilers and the stress corrosion cracking of light alloys are covered. (47 references).

Design and Interpretation of Corrosion Tests. F. L. La Que. (16 pp.) The author gives the theoretical aspects and some practical examples of the tests that should be carried out to choose suitable corrosion resisting materials in processing equipment such as that used in the chemical, paper, and petroleum refining industries. The difficulty of reproducing velocity effects in corrosion testing is shown and some apparently anomalous cooling and heating effects are explained. (23 references).

The Cost of Corrosion. H. K. Worner. (12 pp.) The author itemizes and discusses the expenditure by industrial and private enterprises in combating corrosion. (21 references).

External Corrosion of Gas Mains and Services. G. E. Lewis. (12 pp.) The author discusses design features intended to produce more efficient control of stray currents and outlines briefly the methods being employed to protect the Gas and Fuel Corporation's 18 in. diameter mild steel high pressure gas-line from Morwell to West Melbourne, and the high pressure gas reticulation system at Glenroy.

Special Corrosion Problems in the Gas Industry. R. J. Bennie. (39 pp.) Corrosion problems in the gas industry are discussed with special reference to actions proceeding within the gas stream. Commencing with a brief description of the nature of the attack upon iron and steel by the several corrosive agents present in crude manufactured gases, the author proceeds to outline the parts played by each of them in the corrosion of particular units of gas-making plant, their effects upon plant operation and the measures that have been

adopted in their mitigation. Corrosion problems in both conventional low pressure black coal works and high pressure brown coal gasification plants are discussed. The author also deals with the approach to the corrosion problems within gas distribution systems and some trends in corrosion mitigation in gas-fired equipment. (68 references).

A Method for Assessing the Corrosion of Iron in Soils–Theory of the Soil Probe. K. F. Lorking. (16 pp.) A detailed explanation is given of corrosion processes occurring on iron in aqueous media. A description is given of the theoretical basis of methods for the interpretation of potentials assumed by iron and by platinum electrodes. A soil probe designed to assess rates of corrosion of iron in soils is described and an account is given of experiments carried out to check the principal feature of the probe. (36 references).

Biological Organisms and Corrosion Processes. C. D. Parker. (17 pp.) The corrosion processes associated with the metabolism of a single bacterial species, with inter-related metabolism of two or more different species, and with the products of bacterial fermentation are reviewed. The conditions under which various remedial measures are effective are discussed. (31 references).

Stray Current Electrolysis in Victoria. J. Dunn. (19 pp.) The problem of stray current electrolysis in Victoria has been overcome by adopting controlled electric drainage. The author includes a short description of troubles arising from leakage currents from D.C. electricity supplies. (12 references).

The Passive Behaviour of Iron. W. T. Denholm. (24 pp.) Theoretical and experimental evidence is presented which suggests that both the adsorption and precipitation mechanisms of anodic film formation contribute to the passive behaviour of iron. It is suggested that anodic adsorption occurs when an oxide is stable at a potential more negative than the actual dissolution potential of the metal concerned, so that a film must form by discharge of hydroxyl ions on to surface atoms which remain in their lattice sites. On the other hand, true oxide films are formed at potentials where the metal tends to dissolve so that surface metal atoms may migrate from the metallic lattice into the oxide lattice. The conditions of *p*H and potential under which the adsorption and precipitation mechanisms operate during anodic polarization of iron are shown on a diagram, and the contribution of each mechanism to the passive behaviour of iron is discussed. The effects of alloying elements, accelerators and inhibitors are discussed in terms of their effects on the potentials of the principal anodic processes. (28 references).

Cathodic Protection. W. G. Waite. (29 pp.) The author explains the theory of cathodic protection and describes the specialized equipment which has been developed to allow practical application of the theory. Site investigation and the survey instruments used are discussed and comparison is made between alternative protective methods. The author concludes by summarizing the benefits which cathodic protection can give.

The Mechanism of Anodic Inhibitors of Corrosion : A General Treatment. T. P. Hoar. (16 pp.) The several theories of the anodic inhibition of corrosion and the types of anodic inhibitor are reviewed and an attempt is made to combine them in a comprehensive theory. The fundamental mechanism of the uninhibited anodic process is discussed and it is suggested that the process can be hindered by various kinds of blocking such as (*a*) the formation of impervious, adherent solid films ; (*b*) the formation by precipitation or by direct anodic reactions of solid plugs in pores of films already present ; (*c*) the adsorption of molecules on sites that are otherwise especially ready to undergo anodic dissolution. The joint action of two or more inhibitors in specific cases is discussed. (74 references).

Temporary Corrosion Preventives. E. C. Kuster. (11 pp.) The mechanism of the protective action of corrosion preventives is discussed. Test methods are compared and reasons are given for the choice of the methods used in the Australian specification S.A.A. Interim 61. The selection of the appropriate corrosion preventive for a particular application is discussed.

Volatile Corrosion Inhibitors. A. B. Cox and E. C. Kuster. (12 pp.) The authors review the development and uses of volatile corrosion inhibitors and discuss their inhibiting mechanism. Results of laboratory tests on several of such inhibitors are discussed. (31 references).

Corrosion Problems in the Australian Pulp and Paper Industry. W. T. White. (17 pp.) The corrosion problems encountered are classified as specific failures, general wastage and complex failures. The features of the three groups are described and examples given. The actual or proposed solutions of the problems are outlined. (10 references).

Corrosion in Chemical Industry–The Vital Effect of Microstructure. R. J. T. Caney and B. Henshall. (16 pp.) The paper is divided into three sections which give the authors' experiences on the effects of microstructure on corrosion resistance. Section A deals with the microstructural requirements of iron castings for handling mixtures of sulphuric and nitric acid at temperatures up to about 30° C. Section B covers the phenomenon and causes of intergranular corrosion of 18/8 stainless steel. Section C is a brief summary on the behaviour of alloys of the type 90 per cent. copper 10 per cent. aluminium in boiling 10 per cent. sulphuric acid and boiling 2½ per cent. hydrochloric acid. (10 references).

Corrosion in Petroleum Distribution Plant. N. Boas. (14 pp.) Examples of corrosion in bulk storage equipment, pipelines, and transport facilities are described, together with a suggested approach to the related problems by the corrosion technologist, soil corrosion, stress corrosion, crevice corrosion, differential aeration, galvanic cells are all encountered, and indication is given of where these various cases may be expected. (10 references).

Corrosion Problems in Petroleum Refinery Plant. A. O. Wells. (11 pp.) The problems dealt with are : shell and tube condensers, open type cooler boxes, condensate corrosion and hydrogen attack.

Erosion and Corrosion in Fluid Catalytic Cracking Plants. C. E. Perry and B. J. Rayner. (11 pp.) A brief description is given of the operation of a fluid catalytic cracking plant for crude oil. Erosion in various sections of the plant is discussed and means of minimizing this by design modifications or correct selection of materials are given. Corrosion by sulphur compounds at temperatures above 280° C and hydrogen penetration and blistering are also described.

Corrosion and Deposition in Oil Fired Boilers. R. E. Dow. (24 pp.) The possible methods of formation of SO_3 in flue gas are discussed together with the mechanism of deposition of H_2SO_4 on boiler surfaces. Prevention of corrosion by modifications to design and materials as well as by the use of fuel additives and modification to operating technique is considered. (31 references).

Chemical Aspects of Corrosion Prevention in the Power Station Water-Steam Cycle. W. J. Johnson. (11 pp.) The requirements for corrosion prevention in the water-steam cycle of power stations operating within the 250–650 p.s.i. range are discussed in broad terms. Dissolved oxygen must be kept low and all make-up water purified. Caustic-free phosphate conditioning of boiler waters is advocated. Pure feed water needs no alkali additions. All chemicals should be added directly to the boilers. Regular testing and prompt application of corrective measures are essential. (13 references).

Some Practical and Theoretical Aspects of the Use of Corrosion Inhibitors in Cooling Systems. R. N. Ride. (15 pp.) Chemical and physical factors affecting the successful application of corrosion inhibitors in cooling systems and the characteristics of several commonly used materials are discussed. The mechanism of inhibition is considered and recent work on the mixed phosphate-chromate inhibitor is mentioned, together with a brief account of electrode-potential and corrosion–rate studies on this system being conducted by the author. (22 references).

Corrosion of Boilers Cooling Zinc Concentrate Roaster Gases. A. R. Gordon and J. A. B. Forster. (29 pp.) Corrosion of steel boiler tubes and drums at rates between 100 and 300 mils/year was experienced at the works of the Electrolytic Zinc Company of Australia Ltd., Risdon. Corrosion was caused by sulphuric acid and several suggestions are made regarding the possible causes of the necessarily high sulphur trioxide concentration. Chromium plating and stainless steel sprayed coatings were not completely satisfactory in preventing corrosion. The successful method is the subject of a patent. (32 references).

Corrosion Problems in Nuclear Reactors. K. F. Alder. (14 pp.) An outline of the probable development of nuclear power reactors is presented, with the conclusion that thermal reactors are likely to be the first power producers but that fast breeder reactors will be required in an integrated power

programme. The corrosion problems inherent in graphite and water moderated thermal reactors are discussed in terms of compatibility of coolants, constructional materials and fuels. Emphasis is laid on the accentuation of corrosion caused by increasing operating temperatures, necessitating the use of pressurized gases or pressurized water as coolants. Homogeneous and fast reactors are discussed briefly from the corrosion aspect, with some comments on future developments, particularly in the field of liquid metal coolants. (21 references).

Some Aspects of Corrosion in a Marine Environment with Particular Reference to the Royal Australian Navy. J. F. Bell, M. J. McLachlan and H. A. Laurie. (30 pp.) An attempt is made to define those facets of the corrosion problem which, when taken collectively, are characteristic of the problem in ships. In outlining the methods currently employed by the Royal Australian Navy to combat corrosion, particular emphasis is placed upon the importance of good design and of adequate surface preparation for protective coatings. The authors conclude by indicating the lines along which it is thought future investigations can be directed most profitably.

Observations on Corrosion Protection of Airframe Components. H. E. Arblaster and P. F. F. Thompson. (35 pp.) The author discusses the affect of process variables on corrosion and considers the protection of ferrous, magnesium base and aluminium base alloy components. Constructional steels of the Cr-Mo or Ni-Cr-Mo type are generally protected by cadmium plating for which a zinc chromate primer is usually applied. (30 references).

Paints. Basic Aspects of Corrosion Protection and Weathering. J. R. Rischbieth. (23 pp.) The ways in which the nature and condition of the surface being painted, conditions of exposure, and application requirements affect the selection of a priming paint are discussed. Pigments are classified and their protective actions analysed. (53 references).

Joint Metallurgical Societies' Meeting in Europe, 1955 ; Technical Sessions in Dusseldorf. Inhibition and Inhibitors of Corrosion and Metal Deposition. H. Fischer. (109–113). The author describes the nature of physical and chemical inhibitors of corrosion and metal deposition, and discusses their effect on the fundamental electro-chemical reactions. The ranges of application of the different types of inhibitor are outlined.—G. F.

Resistance to Hot Oxidation of Fe–Cr–Al and Ni–Cr Alloys. M. Signora and F. Baldi. (*Calore*, 1955, **26**, Aug., 346–353). [In Italian]. The authors describe experiments carried out by means of a Chevenard thermobalance to determine the resistance to oxidation of certain alloy steels. Details of the steels investigated are given as well as of the experimental procedure adopted and the apparatus used. (6 references).—M. D. J. B.

The Problem of Corrosion Testing. G. Bolognesi. (*Ing. Mecc.*, 1955, **4**, Oct., 5–7). [In Italian]. A brief outline is given of the problems involved in carrying out corrosion tests. The author stresses the importance of these tests in determining the best materials to use in different circumstances. Results should be critically examined by a specialist to avoid misinterpreting the experimental data.—M. D. J. B.

Electron Diffraction Determination of the Constitution of Oxide Films on the Surface of Iron. J. Moreau and J. Bardolle. (*Compt. Rend.*, 1955, **240**, Jan. 31, 524–526). The constitution of oxide films showing interference colours and formed on the surface of iron in air between 250° and 700° C is similar to that of thick layers prepared under more strongly oxidizing condition. Further, the oxide α-Fe_2O_3 tends to be orientated with the ternary axis of the rhombohedron perpendicular to the surface of the specimen.—G. E. D.

Low Temperature Corrosion by Flue-Gas Condensates. R. W. Kear. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1955, **19**, July, 297–318). A review is made of information on the corrosion of combustion appliances and auxiliaries by flue gases. The causes and mechanism of corrosion are discussed and the results of laboratory and field investigations are presented. The role of sulphuric acid is mainly considered, but hydrochloric acid and oxides of nitrogen are mentioned. (139 references).—D. L. C. P.

Corrosion Protection of Buried Steel. K. F. Trägårdh. (*Tek. Tidskr.*, 1955, **85**, Dec. 13, 1025–1030). [In Swedish]. Details are given of experience concerning the corrosion of tower anchorages obtained by the Swedish hydroelectric board since 1930. Sections deal with the inadequacy of tarring, results obtained with hot galvanizing, galvanizing combined with zinc plate cladding for 200 kV towers, investigations of the corrosive nature of the soil and ground water around towers, soil tests, economics of thicker steel sections to eliminate expensive zinc cladding, and average long-term weight losses. Protection methods are recommended for varying degrees of soil aggressivity.—G. G. K.

A Contribution to the Study of Ferrous Oxide. M. F. Marion. (*Doc. Met.*, 1955, Oct.–Nov.–Dec., 87–136). Detailed results are presented of a comprehensive investigation into the composition and temperature limits over which ferrous oxide is stable. The oxide was prepared both by reacting hydrogen–steam mixtures with iron and by a solid state reaction. The chemical composition of the oxide was determined and correlated with density, lattice parameter, electrical conductivity and melting point measurements. Details are given in the second part of the paper of the analytical methods used to determine metallic iron, and ferrous and ferric iron in the mixtures.—B. C. W.

Investigation on Acid-Resistant High-Silicon Iron. I. H. Sawamura, O. Tajima, K. Akamatsu and H. Muranaka. (*Tetsu to Hagane*, 1955, **41**, Dec., 1265–1271). [In Japanese]. Corrosion rapidly decreases as Si content increases, the max. resistance towards H_2SO_4 being at 15·5% of Si, and towards HCl at 14%. The effects of varying the contents of Si and C were examined, in relation to transverse strength, deflection, ductility, micro-hardness and shrinkage. (23 references).

On the Passivity and Corrosion Resistance of Stainless Steels. M. Pražák and V. Pražák. (*Hutnické Listy*, 1956, **11**, (2), 91–97). [In Czech]. Chemical passivation of metals in oxidizing solutions was compared with anodic passivation, with particular reference to 18/8 steels. On the basis of the researches it is now possible to determine with considerable precision the conditions under which the metal is corrosion resistant, particularly in the passive state. Such determinations can also be made on phases present in alloys in small amounts if a metallographic microscope is used in addition to the oscillographic equipment for recording the polarization curves.—P. F.

The Corrosion of Pit Ropes and its Causes. J. Teindl and E. Hila. (*Hutnické Listy*, 1956, **11**, (2), 77–85). [In Czech]. Corrosion fatigue in pit ropes was studied. The use of tinning and lubricants is recommended; the possibility of copper-plating before drawing of the strands is considered, and certain features in rope production requiring special attention in connection with corrosion fatigue are pointed out.

Corrosion Research Laboratories. VII. Corrosion Work by British Railways Research Department. W. J. Hair. (*Corrosion Techn.*, 1956, **3**, Jan., 8–11). The organization of the British Railways Research Department is outlined and an account is given of how some of the types of corrosion commonly encountered by the B.R. are investigated. The corrosion of rolling stock, paint adhesion problems, structural materials and surface preparation, and the use of aluminium are dealt with briefly.—L. E. W.

Corrosion and Cathodic Protection in Kuwait. J. S. Gerrard. (*J. Inst. Electrical Eng.*, 1956, **2**, Jan., 2–6). The author describes the corrosion environments and problems encountered in Kuwait and then reviews the measures taken by the Kuwait Oil Co. to protect the oil installations.

Research on Salt Fog Corrosion Tests—The Effect of Sample Shape. G. Bianchi and U. Gandolfi. (*Met. Ital.*, 1955, **47**, Dec., 551–554). [In Italian]. The authors show that shape can have a marked effect on the corrosion resistance of samples exposed to salt fog atmospheres. This undesirable effect can be eliminated by conducting the tests with a 3% sodium chloride solution mixed with sodium citrate. A description is given of the circular fog chamber in which the tests were carried out.—M. D. J. B.

Corrosion and the Modern Power Station. E. C. Potter. (*Research*, 1955, **8**, Dec., 450–455). Corrosion and embrittlement phenomena in high-pressure steam boilers are surveyed, and the superior behaviour of Continental steels is noted. A programme of field and fundamental research to elucidate the causes is outlined.—K. E. J.

The Mechanism of Corrosion and Passivation of Metals. M. Pražák and V. Pražák. (*Chem. Listy*, 1956, **50**, (1), 23–28). [In Czech]. The chemical and electrochemical passivation and corrosion of iron in nitric acid of various concentrations were studied, and a diagram showing the rate of corrosion of iron as depending upon the concentration of the acid was

prepared. The experiments show that there is fundamentally no difference between the processes occurring in chemical or electrochemical corrosion reactions.—P. F.

Electrochemical and Corrosion Studies of Zinc in Various Waters. K. Smrček and K. Bartoš. (*Chem. Listy*, 1955, **49**, (12), 1773–1781). [In Czech]. Corrosion studies on zinc in distilled, drinking, industrial and sea waters in the range 20–95° C showed that, with the exception of the last named, an increase in the corrosion potential occurred at 80° C. Various corrosion reactions for zinc were proposed. Maximum attack occurred at 90° C in sea water, at 40° C in industrial water, and at 60° C in drinking water. Zinc of technical purity (98·5%) was used.—P. F.

The Anodic Behaviour of Iron–Chromium Alloys in Sulphuric Acid Solution (2nd Report). Effect of Chlorine Ions in Electrolytes. S. Morioka and K. Sakaiyama. (*Technol. Rep. Tôhoku Univ.*, 1955, **19**, (2), 224–238). The effects of hydrogen and chlorine ion concentration on the anodic polarization curves were studied at 25° C and the mechanism of the hindering effect of chlorine ions on the passivation of iron–chromium alloys was investigated. It was concluded that the latter was due in part to the oxidizing action of chlorine atoms adsorbed by the anode, and in part to the reducing action of chlorine ions against $Cr_2O_7^{--}$ anions.

Calculation of Currents in the Cathodic Protection of Metals. B. Waeser. (*Metall*, 1955, **9**, Dec., 1088–1089). Formulae for the cathodic protective currents are quoted from literature and commented upon.—J. G. W.

Low Temperature Corrosion in Boiler Plants. C. S. Darling. (*Steam Eng.*, 1955, **24**, June, 315–316; July, 352–353; Aug., 395–396; Sept., 428–431; **25**, Oct., 24–27; Nov., 63–66; Dec., 98–99). A series of articles is presented dealing with the causes and prevention of low temperature corrosion in boiler plants, and protection against its attack. The effects in acid attack of different fuels and methods of firing are examined. Corrosion of steel stacks and their preparation for protective coatings are considered. Concrete linings and metallizing are discussed. Finally, the protection and maintenance of brick stacks are described.—T. E. D.

The Fight Against Wear and Corrosion in Site Engineering. M. Signore. (*Costruzioni Met.*, 1955, **7**, Jan.–Feb., 27–36). [In Italian]. The precautions which can be taken to avoid wear of equipment by mechanical action and corrosion are discussed. Most important is the choice of material. The use of Cor-Ten steel is recommended for a wide variety of plant and range of vehicles.—M. D. J. B.

The Anti-Corrosion Packing of Metal Articles According to American Specifications. G. Schikorr. (*Metalloberfläche*, 1955, **9**, June, 84A–88A; July, 104A–107A). A number of American specifications for cleaning and giving temporary corrosion protection to metal articles is outlined, and considerations governing the choice of medium are discussed. In the second article American packing methods are considered.

Electrochemical Thermodynamics and Kinetics. International Committee, 6th Meeting. Poitiers 1954. (*Proceedings* 1955.) **Nomenclature and Definitions,** 20–49. **Utilization of Electrolytic Polishing for the Understanding of the Mechanism of Electrolysis.** I. Epelboin. 94–97. It is concluded that the initial phenomenon of electrolysis is the formation of a layer of adsorbed ions, that the hydration of the ions plays an important part, and that the valency of the ion passing directly into solution can be studied.

Equilibrium Potential—pH Diagrams for Iron at 25° C. E. Deltombe and M. Pourbaix. (118–123). The free energies published by Latimer are used to establish the diagram.

The Equilibrium Potential *p*H. Diagram for the System Fe–CO_2–H_2O at 25° C. E. Deltombe and M. Pourbaix. 124–132. The formation of solid ferrous carbonate is considered and Latimer's free energy values used.

Propositions on the Definition. Nomenclature and Classification of Corrosion-inhibition and Corrosion-inhibitors. H. Fischer. 303–305.

The Passivity of Fe–Cr Alloys. R. Olivier. 314–333. When passivated by anodic dissolution, c.d. × time = const., this product is the coulombs/cm² needed for reaching passivity and is lower for alloys below 14% Cr. An electrochemical process is advanced for the repair of defects in the oxide layer.

Use of Polarization Curves for the Study of the Conditions for Corrosion and Protection of Iron in Presence of Chlorides. A. M. Abd El Wahed and M. Pourbaix. 351–359. Phosphate and chromate in presence of bicarbonate and chloride were studied, and it was shown that corrosion can be predicted from the thermodynamic interpretation of the curves. The method should be generally applicable.

Kinetics of Anode Passivation of Iron in Electrolytes Containing Sulphate. M. Serra and S. Feliu. 360–370. The concentration of SO_4 ion and *p*H have little effect and the process appears to be diffusion-controlled and to originate in strong supersaturation in the immediate neighbourhood of the anode.

The Mechanism of Electrolytic Polishing. S. Feliu and M. Serra. 483–491. A mathematical treatment is developed on the basis that the process is periodic in which saturation alternates with agitation in the diffusion layer.

Corrosion of Carbon Steel in Aluminium Sulphate Solution. On the Corrosion of the Knife of Jordan Engine at Paper Mill. M. Susuma. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, June, 283–287). [In Japanese]. Corrosion by $Al_2(SO_4)_3$ solution is about one-tenth of that produced by H_2SO_4 at the same *p*H, and is markedly increased by the presence of Cu++ ions.

The Applicability of Traube's Rule to the Inhibiting Action of Fatty Acids on Stress Corrosion of Steel. M. Smiatowski and T. Ostrowska. (*Bull. Acad. Polonaise Sci.*, 1954, **2**, No. 7, 345–347). The effect depends upon chain length and is apparently due to adsorbed fatty acid preventing access of corrosive media.

ANALYSIS

Organization of Chemical Testing in Metallurgical Works. B. A. Generozov. (*Zavodskaya Laboratoriya*, 1955, **21**, (4), 506). [In Russian]. The transfer of analytical samples and results in iron and steel works is discussed.—S. K.

On the Volumetric Estimation of Al by means of H_3PO_4–NaOH Titration. T. Honjo. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Feb., 114–117). [In Japanese]. A suggested method depends on forming a ppt. of basic aluminium carbonate from NaOH solution by blowing in CO_2. From this is formed $Al(H_2PO_4)_3$ in phosphoric acid solution, which is titrated with NaOH, using methyl orange. At the end of the reaction $Al(H_2PO_4)_3 + 2NaOH = AlPO_4 + 2\ NaH_2PO_4 + 2H_2O$, a yellow coloration occurs. The method has been used for Al bronze, Mg alloy and nitrided steel.—K. E. J.

Rapid Quantitative Analysis of Nitrogen in Iron and Steel by Absolute Colorimetric Determination and Comparison of Analytical Values of Nitrogen by Several other Methods. S. Kimura. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, June, 300–304). [In Japanese]. Nitrogen in iron and steel can be estimated in 30–55 min, using a Pulfrich photometer and the colour reaction with Nessler's solution. The accuracy is as good as that of the Kjeldahl distillation method, but both methods only give 70–80% of the amount found by the vacuum fusion method.—K. E. J.

Determination of Nitrogen in Steel II. Effect of Aluminium on Determination of Nitrogen in Steel. S. Takano, M. Iida and S. Gotô. (*Nippon Kinzoku Gakkai-Si*, 1954, **18**, Feb., 110–113). [In Japanese]. In determining nitrogen in steel containing > 0·3% of aluminium by the centrifugal separation and photometric method, alkaline distillation is necessary to decompose AlN. This is not necessary when using steam distillation or titrimetric methods.—K. E. J.

Rapid Methods for Distinguishing Pyrites from Marcasite. A. Vendl and T. Mándy. (*Acta. Mineralogica-Petrographica*, 1955, **8**, 63–70). [In German]. Microchemical colour reactions with acid silver sulphate solutions are tabulated, with photomicrographs and X-ray data.

G.E. Seeks Better Understanding of Materials in New Research Laboratory. R. L. Fullman and R. M. Parke. (*Mat. Methods*, 1955, **42**, Oct., 88–91). The experimental plant and activities of the new Metals and Ceramics Building at the G.E.C. Research Laboratory are described. Plant includes 300 lb and 5 lb vacuum furnaces, a one ton electric arc furnace, a 1250 ton extrusion press, various drop hammers, a Sendzimir cold mill and a planetary hot mill. Work is in progress to evaluate the technical and economic feasibility of new processes and materials.—P. M. C.

Toxicity of Metals. Sources of Contamination and Assessment. A. D. Merriman. (*Metal Treatment and Drop Forg.*, 1955, **22**, Mar., 127–131). The effects of metals and alloys, used in the home and in the canning industry, on the flavour and colour of food and the possible injurious effect for human consumption are discussed. Iron and stainless steel are among the metals dealt with, the degree of pickup by various

foods and liquids and an indication of the harmful dosages are considered. (16 references).—P. M. C.

Analytical Applications of the Barker Square-wave Polarograph. D. J. Ferrett and G. W. C. Milner. (*Analyst*, 1955, **80**, Feb., 132–140, 1956, **81**, Apr., 193–203). Part II includes a section on the analysis of steels. Copper, tin and lead can be determined without chemical separations, and the determination is not affected by the valence state of the iron. Chromium can be determined after oxidation to chromate with ammonium persulphate. The chromate peak is recorded from an alkaline mannitol base solution.—T. E. D.

Application of Polarography to the Determination of Vanadium in Steels. F. Burriel Marti and M. Cruz Serna. (*Inst. Hierro Acero*, 1955, **8**, Nov., 625–637. *Special Number*). [In Spanish]. Polarographic analyses have shown that the Stackelberg method for the determination of V gives low, non-reproducible results. A systematic study of prepared Fe-V solutions has been made in an attempt to evaluate the reasons for this result. Alloy elements and temperature are not responsible ; the manner of precipitation of $Fe(OH)_3$ and the *p*H value influence reproducibility. A study of the factors affecting co-precipitations of V with $Fe(OH)_3$ leads to the conclusion that an addition-type method is more reliable. Details of this procedure are given. The solution is fractionated and, to part, a known amount of vanadate is added. Each part after $Fe(OH)_3$ separation is polarographed and the %V calculated. This method is somewhat less precise, though quicker, than the Lingane and Meites method. (22 references).—P. S.

Determination of Molybdenum by Ion Exchange and Polarography. R. L. Pecsok and R. M. Parkhurst. (*Analy. Chem.*, 1955, **27**, Dec., 1920–1923). Polarographic method of determining molybdenum, particularly in steels, in which interfering ions are removed by an ion exchange resin, is described in detail. This permits well defined doublet waves to be obtained for the reduction of Mo (VI) to Mo (V) and Mo (III). Tests on standard steel samples show accuracies of less than 3%.—T. E. D.

Determination of Zinc in Presence of Iron and Nickel. J. Lowen and A. L. Carney. (*Analy. Chem.*, 1955, **27**, Dec., 1965). The use of Amberlite IRA-400 or Dowex-1 ion-exchange resins for the separation of zinc, and its subsequent gravimetric determination using quinaldic acid is described. Iron and nickel are determined separately. The method is particularly useful in the analysis of ferrites.—T. E. D.

Colorimetric Determination of Molybdenum in Tungsten-Bearing Steels. L. J. Wrangell, E. C. Bernam, D. F. Kuemmel, and O. Perkins. (*Analy. Chem.*, 1955, **27**, Dec., 1966–1970). A rapid method for the determination of 0·24% or more of molybdenum in tungsten-bearing steels is described. The method provides for the retention of tungsten in solution, the elimination of interfering light absorption by the thiocyanate complex of reduced tungsten, and the use of a chromium correction factor. Good accuracy is obtained, and analysis time is approximately 1 hour.—T. E. D.

Estimation of Tin in Iron and Steel Products. J. Migeon. (*Chim. Analy.*, 1955, **37**, Dec., 416–421). The polarographic determination of tin in very small quantities in iron and steel is studied. The determination is carried out in perchloric acid–sodium chloride medium after separation of the tin by distillation. Practical details of the method are given.

Photometric Determination of Niobium and Tantalum in Steel. A. Eder. (*Arch. Eisenhüttenwesen*, 1955, **26**, Aug., 431–435). After a brief review of the literature, the author discusses the production of coloured solutions of niobium and tantalum with pyrogallol. Both elements form solutions coloured or otherwise according to the hydrogen ion concentration. Appropriate additives enhance the coloration. Calibration curves and experimental procedure are given, and the effect of titanium on the method is described.—A. C.

Spectrographic Analysis of Slags. N. V. Buyanov. (*Izvest. Akad. Nauk SSSR, Seriya Fiz.*, 1955, **19**, (1), 89–93). Seven existing methods are reviewed and a recommended method is given. Limits are shown for SiO_2, CaO, FeO, MnO and the V, Cr, Si, Al, Ca, Mg, Fe and Mn in 4 slags are tabulated including chromes with and without flux.

Spectrographic Analysis of Slags with Use of Flux. E. N. Lesnikova. (*Izvest. Akad. Nauk SSSR, Seriya Fiz.*, 1955, **19**, (1), 97–98). Borax is used at 800–850°.

Spectrochemical Method of Analysis of Open-Hearth Slag for all Basic Components. O. I. Nikitina. (*Izvest. Akad. Nauk SSSR, Seriya Fiz.*, 1955, **19**, (1), 94–96). Methods for briquettes and solutions are given with the wave-lengths recommended for CaO, SiO_2, MnO, FeO, Al_2O_3 and MgO.

Spectrographic Analysis of Nickel Production Slags over a Wide Range of Concentrations of the Components. D. M. Shvarts and I. S. Nilova. (*Izvest. Akad. Nauk SSSR, Seriya Fiz.*, 1955, **19**, (1), 96–97). Analyses on briquettes and solutions are briefly described and the wave-lengths given in each case with comparison lines of copper for the former and molybdenum for the latter.

Spectrographic Method for Analysis of Alumina. L. B. Drutskaya. (*Izvest. Akad. Nauk SSSR, Seriya Fiz.*, 1955, **19**, (1), 103–104). Arc and spark methods are given for mixtures with sand and clays.

Volumetric Methods of Technical Gas Analysis used in the Iron Industry. J. Morsing. (*Stat. Prorn. Medd.*, 1954, 116, pp. 54). After a general review of apparatus and absorbents, an Orsat apparatus is described and its findings compared with gravimetric figures.

INDUSTRIAL USES AND APPLICATIONS

These Hot Work Die Steels Look Promising for Aircraft Structures. E. A. Loria. (*Mat. Methods*, 1955, **42**, Aug., 94–97). The author suggests that certain steels originally developed for the tool and die industry might be worthy of consideration for modern aircraft structures. Four such steels are discussed—Halcomb 218, Chro-Mow, Halcomb 1370 and Peerless J. These are products of the Crucible Steel Co. U.S.A., containing various amounts of chromium, vanadium, tungsten and molybdenum. Their properties at temperatures up to 1200° F are outlined and tabulated. (6 references).

Steels for Power Stations. (*Nat. Phys. Lab. Report for* 1955, 60–61). A brief review of work on ferritic steels for service above 600° C.

New Techniques Used in the Reconstruction of Steel Bridges for the German Motor Roads. W. Wolf. (*Acciaio Costruzioni Nat.*, 1955, **7**, Oct.-Nov., 12–15). [In Italian]. This article describes new techniques in the design of steel bridges for motor roads.—M. D. J. B.

Sheet Metal Work—A Guide to Examination Requirements. A. Dickason. (*Sheet Metal Ind.*, 1953, **30**, Aug., 633–639 ; Sept., 781–783 ; Oct., 857–862, 902 ; 1954, **31**, Jan., 55–60 ; Apr., 279–283 ; May, 372–377). This series of articles is intended for students and young craftsmen, and covers Geometry and Pattern Development, Science, Materials and Processes, Trade calculations, and Workshop Practice. Examination syllabuses for such Institutes as the City and Guilds of London are discussed, and typical examination questions at all levels in all the above subjects are answered in detail.—P. M. C.

Carbon-Molybdenum-Phosphorus Steels for Superheater Tubes. N. Collari. (*Calore*, 1955, **26**, Jan., 37–43). [In Italian]. The author discusses the advantages which may accrue from small additions of phosphorus (max 0·20%) to low carbon steels, particularly when these are to be submitted to high temperatures. Reference is made to the work of other investigators. Details of different specifications for superheater tube types of steels are given and their mechanical characteristics are discussed. (14 references).—M. D. J. B.

Sulzer Investment Cast Turbo Rotors and Blades. F. Eisermann. (*Sulzer Tech. Rev.*, 1955, **37**, No. 3, 19–33). Composition, heat-treatment, creep tests, and thermal shock are described.

Structural Materials for Heat Transfer in Nuclear Reactors : Selecting Materials for Liquid Sodium Systems. R. F. Koenig and E. G. Brush. (*Mat. Methods*, 1955, **42**, Dec., 110–114). Liquid sodium is used as a coolant in some types of nuclear reactors. Problems associated with its use include the transfer of radioactivity, mass transfer, mechanical and corrosive effects. The authors discuss the suitability of different materials used in the construction of plant coming into contact with sodium, and the effects of impurities in the sodium itself. Austenitic stainless steels of the 18/8 type have been most widely used. The resistances of many materials, both metallic and non-metallic, to sodium attack are given in tabular form. (5 references).—P. M. C.

Plastic–Metal, Competition or Co-operation. G. Philipson. (*Värm. Bergsmann. Ann.*, 1955, 75–95). [In Swedish]. The author reviews the developments which have taken place in

plastics mainly during the last 30 years, and gives statistics for plastics and metal production during 1953. Details are given of possible applications and characteristics of the nine main types of plastics, and it is concluded that, on the basis of past experience, metals are hardly likely to be ousted to any great extent.—G. G. K.

Permanent Magnet Production. (*Elect. Times*, 1955, **128,** Dec. 22, 958–959). Extensions recently made in the works of James Neill and Co. of Sheffield to deal with the increasing demand for permanent magnets are described.—L. D. H.

HISTORICAL

The Mirandaola Forge ; Legend from the Middle Ages. (*Metal Treatment and Drop Forg.*, 1955, **22,** Sept., 384–386). Illustrations and a description are given of the Mirandaola forge, one of 25 " ferrerias mayores " in the Legazpia district of Spain in the 14th and later centuries. This forge, to which a legend concerning a pure iron cross is attached, was reconstructed in 1952. An interesting description of the method of smelting and forging iron under a water-driven helve hammer is given.—P. M. C.

The " Fanderias " in Spain. J. Almunia y de Leon. (*Inst. Hierro Acero*, 1955, **8,** Oct.-Dec., 810–819). [In Spanish]. Fanderias were the splitting mills discussed in Spain in 1590, and again in 1616, but not introduced until 1769. This first mill worked with two reverberatory furnaces (fired with good English coal) for seven months of the year, averaging 65,000 lb production weekly. Later others were built. Their replacement by the true rolling mills was delayed until 1829 by the European wars. (12 references).—P. S.

Isaac Wilkinson (c. 1705-1784) of Bersham, Ironmaster and Inventor. A. S. Davies. (*Trans. Newcomen Soc.*, 1949–50 and 1950–51, **27,** 69–72).

Early Ironmaking in the Sheffield Area. R. A. Mott. (*Trans. Newcomen Soc.*, 1949–50 and 1950–51, **27,** 225–235). An historical account of the ancient bloomeries with brief notes on the 17th and 18th centuries.

The First Successful Bessemer Steel. K. F. Goransson. (*Metal Progress*, 1956, **69,** Jan., 85–87). A brief historical account of the successful manufacture in 1858 of Bessemer steel in Sweden is given.—B. G. B.

Monks as Ironmasters. F. W. Robins. (*Edgar Allen News*, 1955, **34,** Oct., 233–234). The activities of early British ironmakers are described.—D. L. C. P.

Further Excerpts from the Correspondence of a XIXth Century Ironfounder. T. R. Harris. (*Found. Trade J.*, 1955, **99,** Dec. 1, 641–642). Some excerpts from the correspondence of a nineteenth century Cornish ironfounder are presented to illustrate the changing conditions in the foundry in the latter half of the century.—B. C. W.

An Historic Forging Community in Kropa, Yugoslavia. F. Baš. (*Stahl u. Eisen*, 1955, **75,** Oct. 20, 1393–1397). The author discusses the production of iron in the region to the south-east of the common frontiers of Italy, Austria, and Yugoslavia in prehistoric and early historic times. Existing remains of primitive equipment, and the living and working conditions in an iron-settlement, are described.—A. C.

Johann Georg Ludolph Blumhof and His Encyclopaedia of the Metallurgy of Iron and Steel. H. Dickmann. (*Arch. Eisenhüttenwesen*, 1955, **26,** Aug., 427–429). Blumhof's life and the historical significance of his encyclopaedia are discussed.—A. C.

A Hundred Years of Metallurgy. L. Granger and J. Papier. (*Doc. Met.*, 1955, Special Centenary Number, (22), 5–28). The development of ferrous metallurgy in the last 100 years is described largely by reference to papers published in the Bulletin de la Société de l'Industrie Minérale over this period. The emphasis is on the production and fabrication of steel.—B. C. W.

The Age of Wrought Iron. E. H. Schulz. (*Arch. Eisenhüttenwesen*, 1955, **26,** July, 365–371). The author discusses the varieties of malleable iron used in the course of historical development, and refers to the decline in quality with the advent of the puddling technique.—A. C.

ECONOMICS AND STATISTICS

The Australian Iron and Steel Industry's Post-War Expansion—(IV). The Steel-Using Subsidiaries. N. R. Wills. (*B.H.P. Rev.*, 1955, **33,** Dec., 2–10). A short description of the history and present position of the steel wire-producing and processing subsidiary companies of B.H.P. is given. The article concludes with a description of the B.H.P. coal chemicals and by-products plants.—L. D. H.

The Australian Iron and Steel Industry's Post-War Expansion—(III). B.H.P.'s Newcastle Steel Works—Forty Years of Achievement. N. R. Wills. (*B.H.P. Rev.*, 1955, **32,** June–Sept., 22–31). The history of the Newcastle works of B.H.P. prior to 1939 is outlined, and developments during and since the war are described, with some reference to expansion in Southern Australia.—L. D. H.

The European Coal and Steel Community. D. P. Spierenburg. (*Jernkontorets Ann.*, 1955, **139,** 11, 863–884). [In English]. A general account is given of the functions of the Community, of work undertaken to open up a common market and to improve working conditions in each of the member industries, of lessons learned in the economic sphere, and of the effect which the Community has on non-member countries.—G. G. K.

Iron and Steel Developments in the State of Minas Gerais (Brazil). *Rev. Quim. Industr.*, 1955, **24,** June, 32). [In Portuguese]. Following a brief historical review, some details are given of the present state and the future plans of the steel industry in Minas Gerais. Figures planned for 1957 are 810,000 metric tons of pig iron, 700,000 tons of steel, 530,000 tons of rolled products. Development of electric power and of sinter production are the two most important factors. An intensive forestry programme will also help the fuel position.—R. S.

The U.K. Steel Tariff. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Mar., 5–8). The U.K. tariff on steel has been suspended for a considerable range of products owing to shortage of steel. The article describes the history of the tariff and the form which it might conceivably take in future.—E. C. S.

Steel in Scotland. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Apr., 5–11). Scotland is responsible for just under one-eighth of U.K. crude steel output. The somewhat limited supply of local coking coal sets a limit to the possible output of pig-iron at reasonable cost. However, it is expected that steel production will reach some 2·6 million ingot tons and pig-iron production 1·2 million tons by 1958.—E. C. S.

Steel on the North East Coast. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** July, 5–15). In 1954, this area accounted for just under a quarter of the U.K. output of pig-iron and one-fifth of the national crude steel production, and was the main producer of heavy rolled products. Between 1953 and 1958, over £60 million is to be spent on new capital developments in the area; pig iron and steel production should rise to 3,650,000 tons and 4,750,000 tons respectively.—E. C. S.

Steel in South West Russia. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Nov., 5–13). The article is based on a memorandum prepared by the Federation for the use of British members of an international delegation which recently visited the iron and steel industry of South West Russia under the auspices of E.C.E. Three sections: I Steel Plants, II Production Policy, III Post-war Plans, and an appendix on raw materials are included.—E. C. S.

Steel Developments in France. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Aug., 5–14). The French steel industry's second post-war development plan was recently published by the Iron and Steel Modernization Committee of the Planning Commission, the body which advises the Prime Minister on the development of French industry. The plan is surveyed in detail. The plan states that a crude steel output of 14·3 million tons should satisfy home and export requirements in 1957.—E. C. S.

Efficiency in the Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Sept., 5–10). This subject is discussed under the following headings:—economy in raw materials, fuel economy, economy in plant and equipment and economy of labour. While output has risen by five eighths since the war, the number of workers employed has risen by no more than one eighth.—E. C. S.

The Indian Steel Industry. (*Brit. Iron Steel Fed. Monthly Stat. Bull.*, 1955, **30,** Feb., 5–21). The survey describes India's existing iron and steel industry and summarizes the various proposals for new capacity to bring steel production to 6 million tons a year. At least three new million-ton works are likely to be built, whilst a proposal for a fourth large plant has been made. Steel production in 1952—the peak post-war year—was only 12% above the 1941 figure, whilst pig-production is still below that recorded in 1941.

The Post-war Development of Iron and Steel Industry in Japan. T. Mitsui. (*Tetsu to Hagane*, 1955, **41**, July, 682–695). [In Japanese]. The economic development of the industry is surveyed, in the light of world events and foreign market trends, with particular reference to the 1951 rationalization and financing schemes for the industry, raw materials trends, developments in special steels, and prospects.—K. E. J.

Report on Choosing a Position for a Seamless Tube Mill in Brazil. E. L. da Fonseca Costa. (*Bol. INT.*, 1953, **4**, Sept., 3–19). [In Portuguese]. This report was drawn up for submission to the Brazilian authorities in relation to the case for a seamless tube mill in the State of Minas Gerais. The purpose of this article is to serve as an example of how such a case should be presented to the authorities. Initial production was to be 60,000 tons a year. The economic factors such as raw materials, electric power, fuel, wages and transport were examined. Steel production was to be based on the Tysland-Hole or Siemens electric furnace using charcoal or coke breeze from Volta Redonda.—R. S.

The Metallurgical Industry of São Paulo within the Complex Metallurgy of Brazil. A Conference at the Institute of Engineering in São Paulo. (*Bol. Geol. Met.*, 1954, **9**, (12) 47–102). The steel production of Brazil is discussed. Although production of ingots has been steadily rising each year (from 206,000 tons in 1945 to 1,002,000 tons in 1953) the total consumed expressed on a per capita basis over the total population of 54 million has only reached 20 kg. This compares with 600 kg for the U.S.A., 160–380 kg for European countries and 42 kg for Spain. It is pointed out that the future establishment of car producing factories in Brazil by two different American companies and two different German companies will greatly increase the steel requirements. Graphical pictures of the quantities of raw materials and the steel output at various stages in the steel works per annum are shown. Further sketches illustrate the geographical distribution of the raw materials, coal, ore, and limestone, in Brazil and the transport distances to the steel works. The distribution of the steel products to factories and population centres in Rio de Janeiro and São Paulo is also examined.—J. R. P.

A Study of the Mineral and Metallurgical Problems of Brazil. A Conference at the Institute of Engineering in São Paulo. (*Bol. Geol. Met.*, 1953, **8**, (10), 61–115). The coal and iron-ore resources and qualities in Brazil are discussed. In 1951, 1,139,000 tons of steel products were consumed in the country, of which 364,000 tons were imported from Europe. The steel works at Volta Redonda has two blast furnaces (one of 1,200 tons daily output) and four open-hearth furnaces. The present capacity of the works is 950,000 tons per annum of ingots but it is estimated that by 1960 the national requirements will have increased to 2,580,000 ingot tons (including 1,931,000 tons sheet steel) per annum. Hence a three-fold expansion of the steel works will be necessary by 1960.—J. R. P.

Iron and Steel Industry in Europe 1955. Organisation for European Economic Co-operation. (*Trends in Economic Sectors*, 1956, pp. 122). Statistics of production and price trends are shown for the second half of 1954 and the first half of 1955.

High Quality of Planning. M. I. Antipov. (*Stal'*, 1955, (3), 195–198). [In Russian]. The recent activities of the Planning Department of the Ferrous Metallurgy Ministry, of which the author is Head, are reviewed and instances of projects planned are given.—S. K.

Three Steps Forward. (*Brit. Steelmaker*, 1955, **21**, Aug., 258–262). Three recent innovations at Steel, Peech and Tozer represent considerable advances towards automation in steelworks practice. They are: (i) the quantometer, used for rapid analysis of steels, sinters, and slags; (ii) a new axle forge with an output of more than 100 axles per shift; and (iii) a new ring-rolling plant producing 60 rings/h, ranging from 5 in. to 50 in. dia. The principles of operation and application to production of the quantometer are described, and the layout and sequence of operations of the two new plants are discussed.—G. F.

Examples of Various Applications of Statistical Methods. M. Guenot. (*Institut de Statistique de l'Université de Paris: Journée de la Sidérurgie*, 1954, June 22, 13–17). Statistical methods are applied to the analysis of coal, shock resistance tests, and a comparison of steelmaking methods.—T. E. D.

MISCELLANEOUS

Science and Enterprise in the Iron and Steel Industry. H. Schenck. (*Iron Coal Trades Rev.*, 1956, **172**, Jan. 6, 31–34). The author discusses the uses and application of fundamental research in iron and steel production, and answers recent criticism of the value of fundamental physico-chemical research.—G. F.

The Need for Improving the Organization of Managerial Production Control in Ferrous Metallurgy. (*Stal'*, 1955, (5), 387–390). [In Russian]. Existing organizational shortcomings of ferrous-metallurgical works managements are discussed, including the non-adoption of the new, standard technical documentation system.—S. K.

Metals of High Purity. J. C. Chaston. (*Metal Progress*, 1956, **69**, Jan., 64–67). Five chemical and six thermal methods of removing solid and gaseous impurities from metals are discussed with examples of the results obtained.—B. G. B.

Surface Diffusion. R. L. Bond and A. R. Murnaghan. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1954, **18**, Sept., 413–421). This review is concerned with the evidence that adsorbed films of gases and vapours are mobile, and with the methods by which the rate of diffusion of such films can be measured. (49 references).—D. L. C. P.

Dangers to the Health of Men and their Prevention. O. Kroh. (*Grosse Schweisstechn. Tagung, Frankfurt*, 1955, 1–6). The danger of occupational diseases and overcoming their effects are discussed from the psychological point of view.—U. E.

Effluent Disposal Problems in the Chemical and Allied Industries. M. Lovett. (*Chem. Process Eng.*, 1956, **37**, Mar., 86–90, 95). The author indicates the way in which effluent disposal problems might be approached and gives examples of treating effluents by physical, chemical and biological means. In one plant the wastes from iron and steel pickling are treated with milk of lime to precipitate ferric hydroxide sludge. The author recommends filter-pressing as the most satisfactory method of dealing with this sludge. The removal of cyanide from metal plating wastes by treatment with ferrous sulphate, by chlorination, or by oxidation is dealt with.—L. E. W.

Use of Statistical Mathematics in Steelworks. G. Strohmeier and H. Richter. (*Stahl u. Eisen*, 1955, **75**, Nov. 3, 1494–1501). Statistical mathematics was applied to a wide range of technical problems during the second world war. The leading ideas and techniques are illustrated by means of practical examples taken from the iron and steel industry. The prospect of development in the solution of certain metallurgical problems is reviewed, with a specimen prediction of the output of a new cogging mill. Probability theory and the use of electronic computers are discussed.—A. C.

A New Process for the Production of Nickel in Brazil. (*Rev. Quim. Industr.*, 1955, **24**, Aug., 31). [In Portuguese]. The Brazilian Mineral Production Laboratories have announced a new method for the production of nickel as a result of research at Liberdade (Minas Gerais). The process is hydro-metallurgical based on molecular disorder of the ore, followed by lixiviation and electrolysis to obtain the metal.

Inauguration of the First Tungsten Plant in Latin America. (*Rev. Quim. Industr.*, 1954, **23**, Nov., 33). [In Portuguese]. This is a short descriptive note on the General Electric S.A. tungsten plant opened in Rio de Janeiro in November, 1954 to produce 0·041 in. diameter tungsten wire for an output of 42 million lamps per year.—R. S.

The Solubility of Oxygen in Water. L. M. Zoss, S. N. Suciu and W. L. Sibbitt. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, 69–71). The solubility of oxygen in water has been measured at pressures of 1000, 1500 and 2000 psia and temperatures from 32–625° F.—D. H.

Experience Obtained by those using New Methods Must Be Made Generally Available. (*Stal'*, 1955, (4), 291–294). [In Russian]. Three inter-works schools were organized in the U.S.S.R. during 1954 on the most advanced practice. One school was on blast-furnace operation and dealt with high top-pressure operation, the use of high blast-temperatures, improvements in charging, control and maintainance. Another course dealt with O.H. furnace operation and maintenance with special reference to the installation of new hearths and fettling. In the third school the preparation of metal for rolling and the treatments of the finished product were discussed.—S. K.

AMERICAN IRON AND STEEL INSTITUTE. "*Forged Railway Axles.*" (Steel Products Manual). 4to, pp. 96. New York, 1956: The Institute.

AMERICAN SOCIETY FOR METALS. "*Theory of Alloy Phases.*" A Seminar on Theory of Alloy Phases held during the Thirty-seventh National Metal Congress and Exposition, Philadelphia, October 15 to 21, 1955, sponsored by the American Society for Metals. 8vo, pp. iii + 378. Illustrated. Cleveland, Ohio, 1956: The Society. (Price 47*s.* 9*d.*).

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